University of Calgary
Space Architecture
& Systems Architecting

Kriss J. Kennedy
NASA - Space Architect
February 7, 2017

Career as a Space Architect

Space Architect 29 yrs @ NASA-JSC

Worked on over 45 designs and projects

Written over 50 publications, papers, or chapters in books

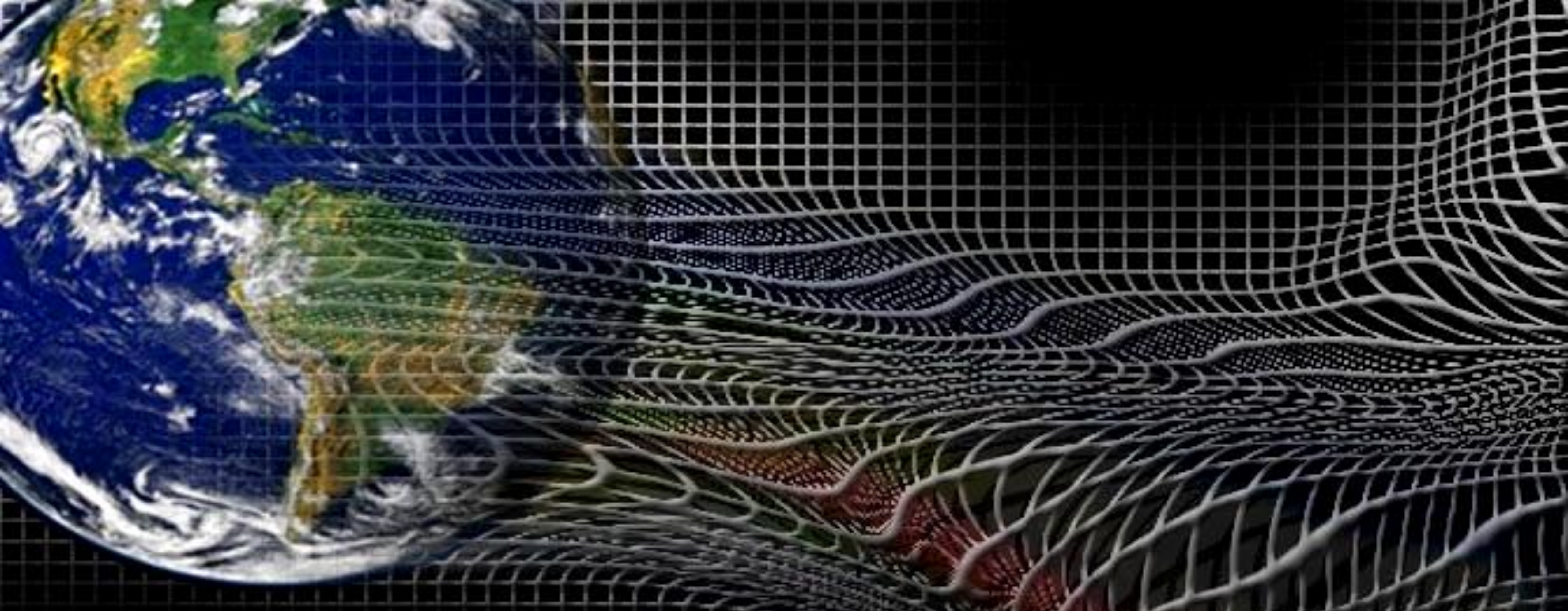
published in numerous magazines, periodicals & books

Has two patents and numerous NASA Technology Brief Awards

Recognized by his architect peers as one of the new upcoming architects in Texas as published in the millennium issue January 2000 Texas Architect magazine.

First space architect awarded the prestigious Rotary National Award for Space Achievement in March 2000

Registered licensed architect in the State of Texas



Current Roles:

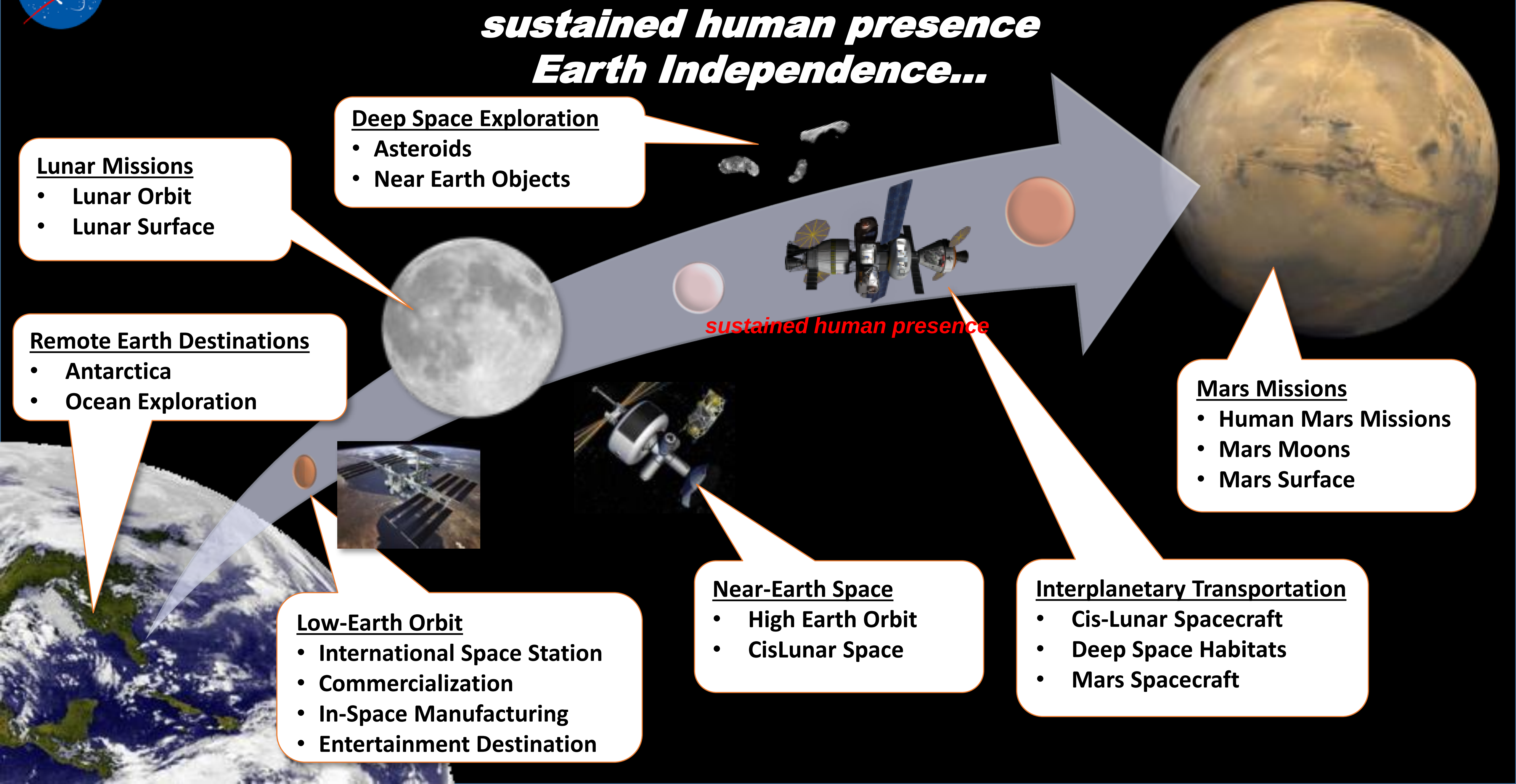
1. **Human Health & Performance and Human Research Program Lead on the Proving Grounds Definition-Future Capabilities Study**
2. ***Project Manager: CisLunar Ph-1 Habitat Internal Architecture Design***
3. ***Adjunct Professor, Univ of Houston-SICSA Space Architecture***

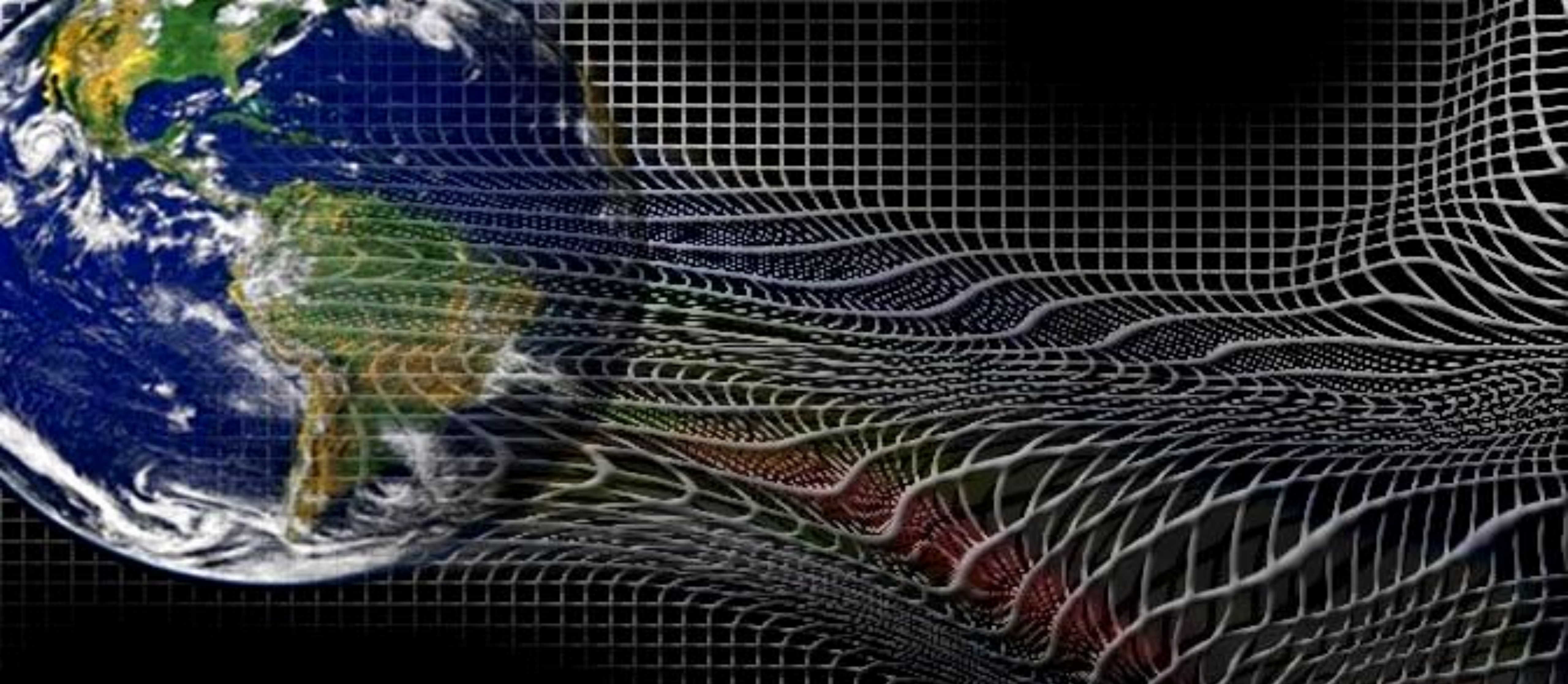
Space Architecture…

…theory and practice of designing and building inhabited environments in outer space…

….design of living and working environments in space related facilities, habitats, surface outposts and bases, and vehicles…

Human Exploration Destination Systems



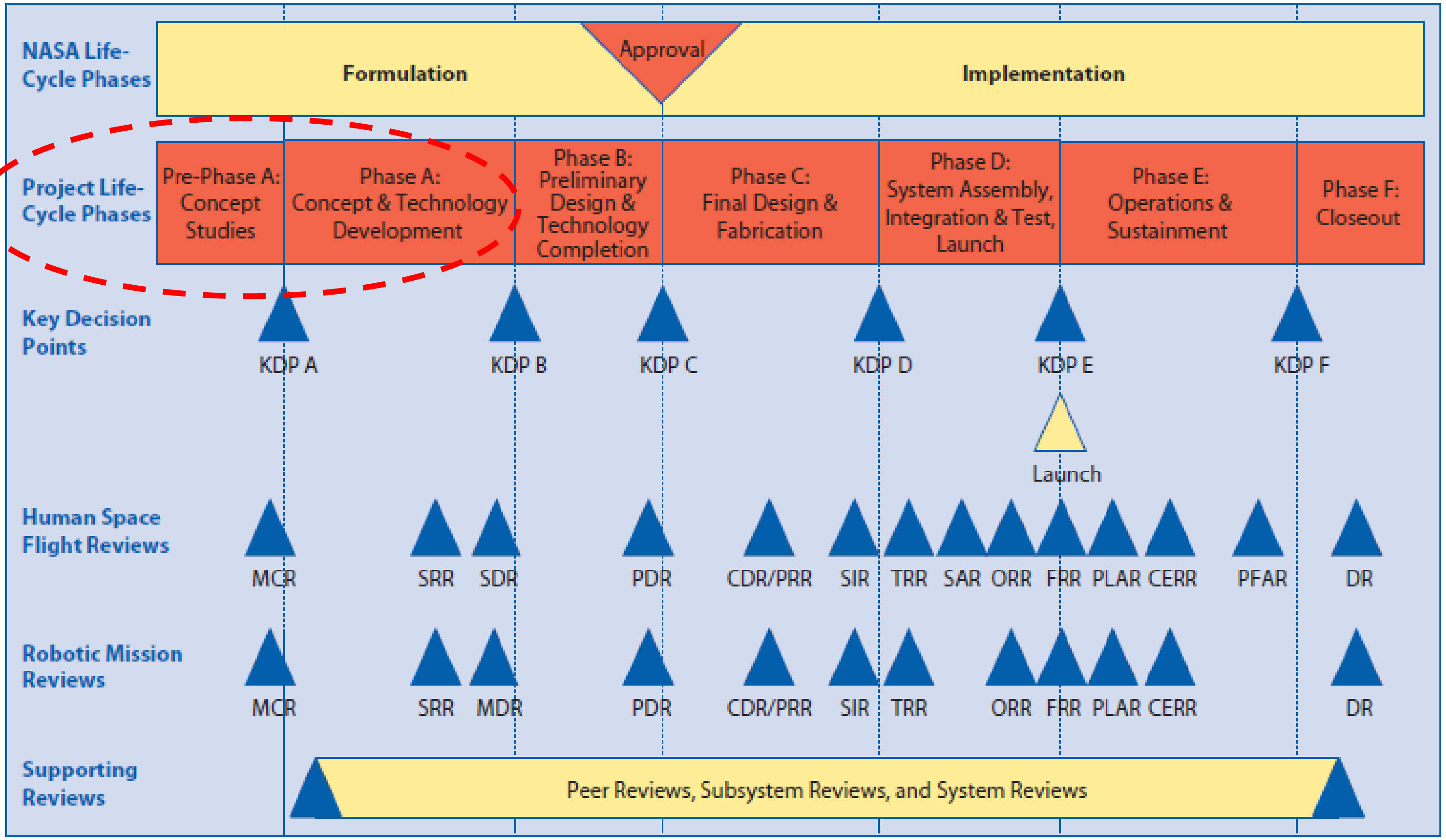


Systems Architecting

Systems Engineering & Integration

NASA Project Life Cycle

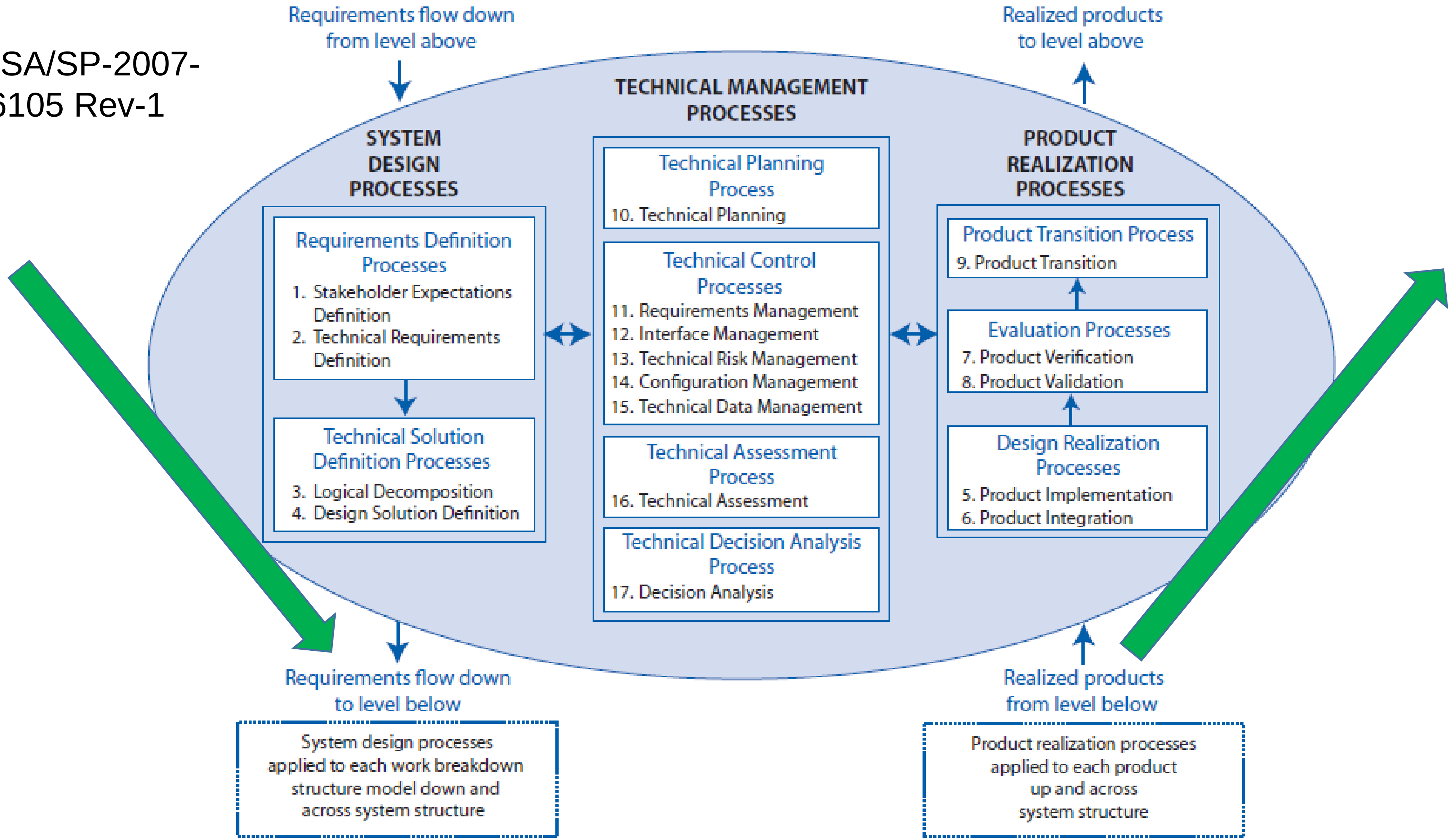
Conceptual Design



CDR	Critical Design Review
CERR	Critical Events Readiness Review
DR	Decommissioning Review
FRR	Flight Readiness Review
KDP	Key Decision Point
MCR	Mission Concept Review
MDR	Mission Definition Review
ORR	Operational Readiness Review
PDR	Preliminary Design Review
PFAR	Post-Flight Assessment Review
PIR	Program Implementation Review
PLAR	Post-Launch Assessment Review
PRR	Production Readiness Review
P/SDR	Program/System Definition Review
P/SRR	Program/System Requirements Review
PSR	Program Status Review
SAR	System Acceptance Review
SDR	System Definition Review
SIR	System Integration Review
SRR	System Requirements Review
TRR	Test Readiness Review

NASA Systems Engineering Overview

NASA/SP-2007-6105 Rev-1



NASA Systems Engineering Handbook

NASA/SP-2007-6105 Rev1

Systems engineering is a methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system. A “system” is a construct or collection of different elements that together produce results not obtainable by the elements alone. The elements, or parts, can include people, hardware, software, facilities, policies, and documents; that is, all things required to produce system-level results.

Synergy is the creation of a whole that is greater than the simple sum of its parts. The term *synergy* comes from the Attic Greek word συνεργία *synergia*[1] from *synergos*, συνεργός, meaning "working together".

Systems Engineering

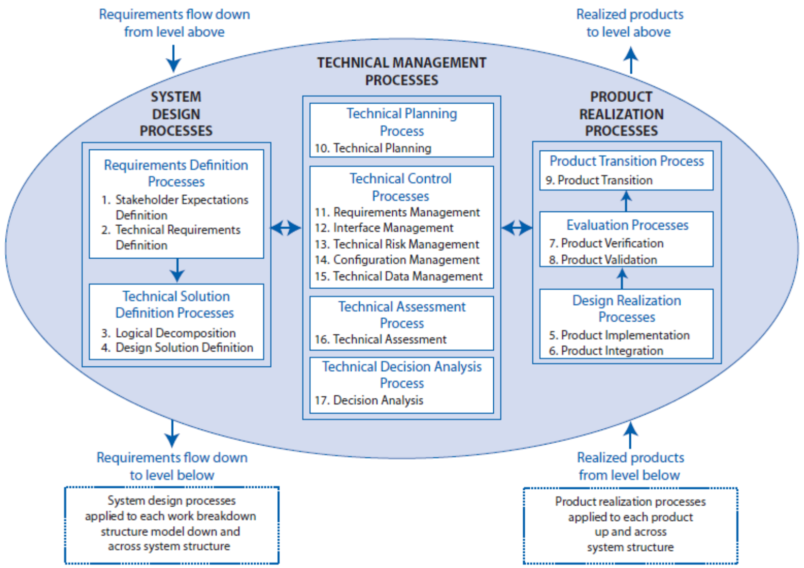
- Systems engineering is an interdisciplinary field of engineering that focuses on how to design and manage complex engineering systems over their life cycles. Issues such as requirements engineering, reliability, logistics, coordination of different teams, testing and evaluation, maintainability and many other disciplines necessary for successful system development, design, implementation, and ultimate decommission become more difficult when dealing with large or complex projects. Systems engineering deals with work-processes, optimization methods, and risk management tools in such projects. It overlaps technical and human-centered disciplines such as industrial engineering, control engineering, software engineering, organizational studies, and project management. Systems engineering ensures that all likely aspects of a project or system are considered, and integrated into a whole.
- The systems engineering process is a discovery process that is quite unlike a manufacturing process. A manufacturing process is focused on repetitive activities that achieve high quality outputs with minimum cost and time. The systems engineering process must begin by discovering the real problems that need to be resolved, and identify the most probable or highest impact failures that can occur - systems engineering involves finding elegant solutions to these problems.
- https://en.wikipedia.org/wiki/Systems_engineering

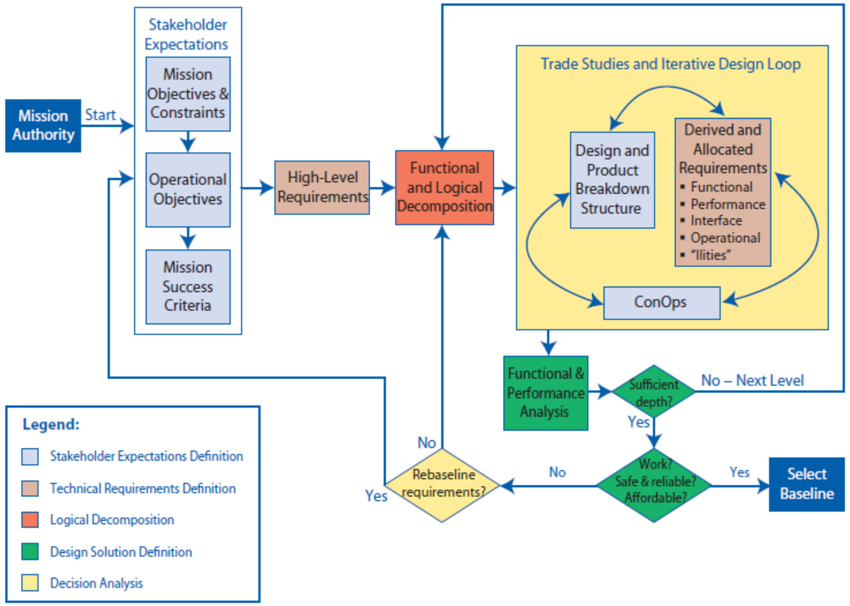
Systems Architecting (Systems Engineering)

1. Understand the design space: define the design constraints
   a) Programmatic, Strategic, Ground Rules and Assumptions
2. Understand the customer, stakeholders, and users
   a) Concept of Operations, Test Objectives, Human System Integration
3. Define the Functional & Performance requirements. Decomposition of functions…
4. Brainstorm/Define Mission Concept Alternative Architectures
5. Perform Trade Studies & System Analysis
6. Define Interfaces
7. Brainstorm Element & System Concepts: Conceptual Design

…

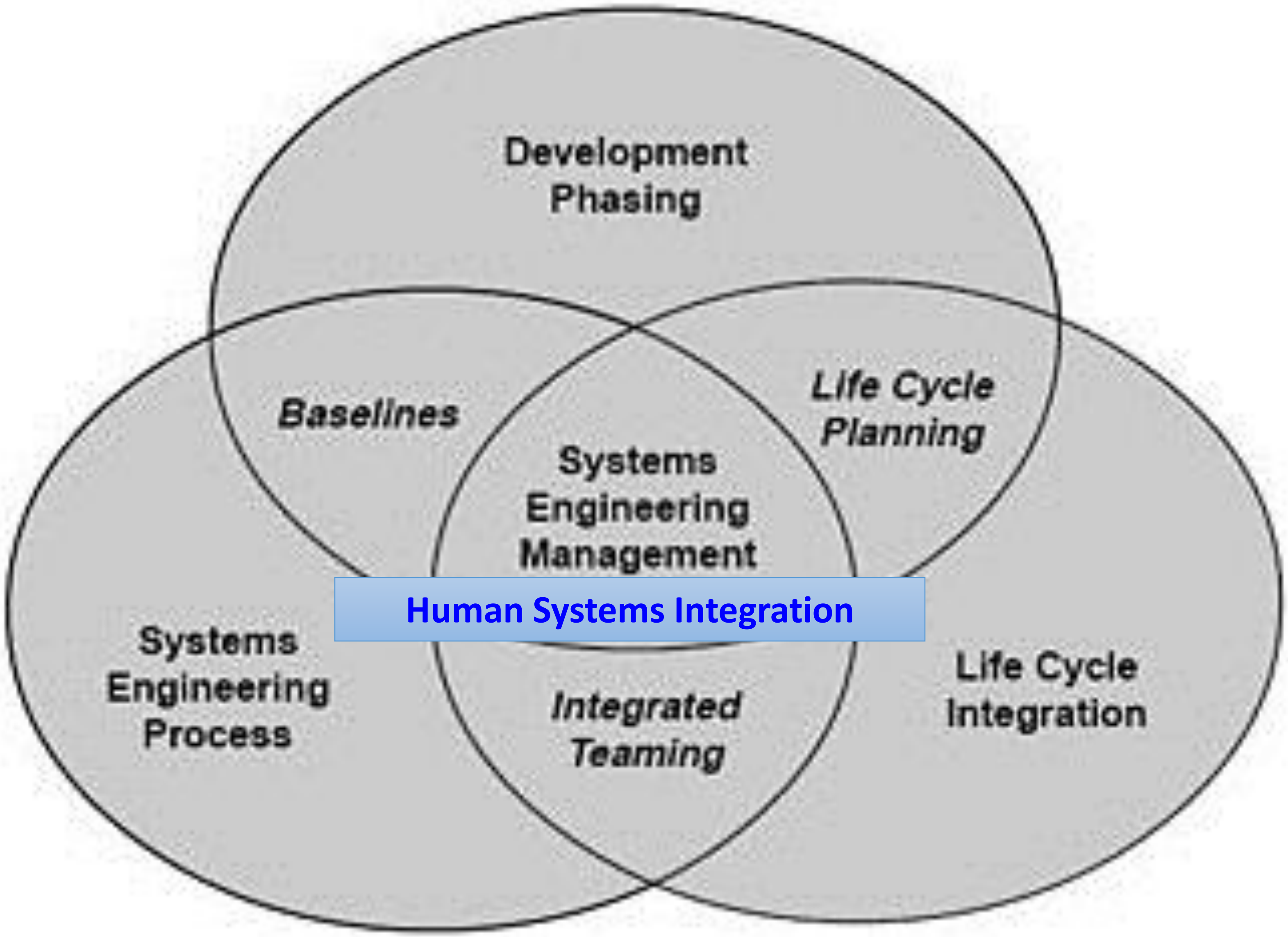
Systems Architecting (Systems Engineering)



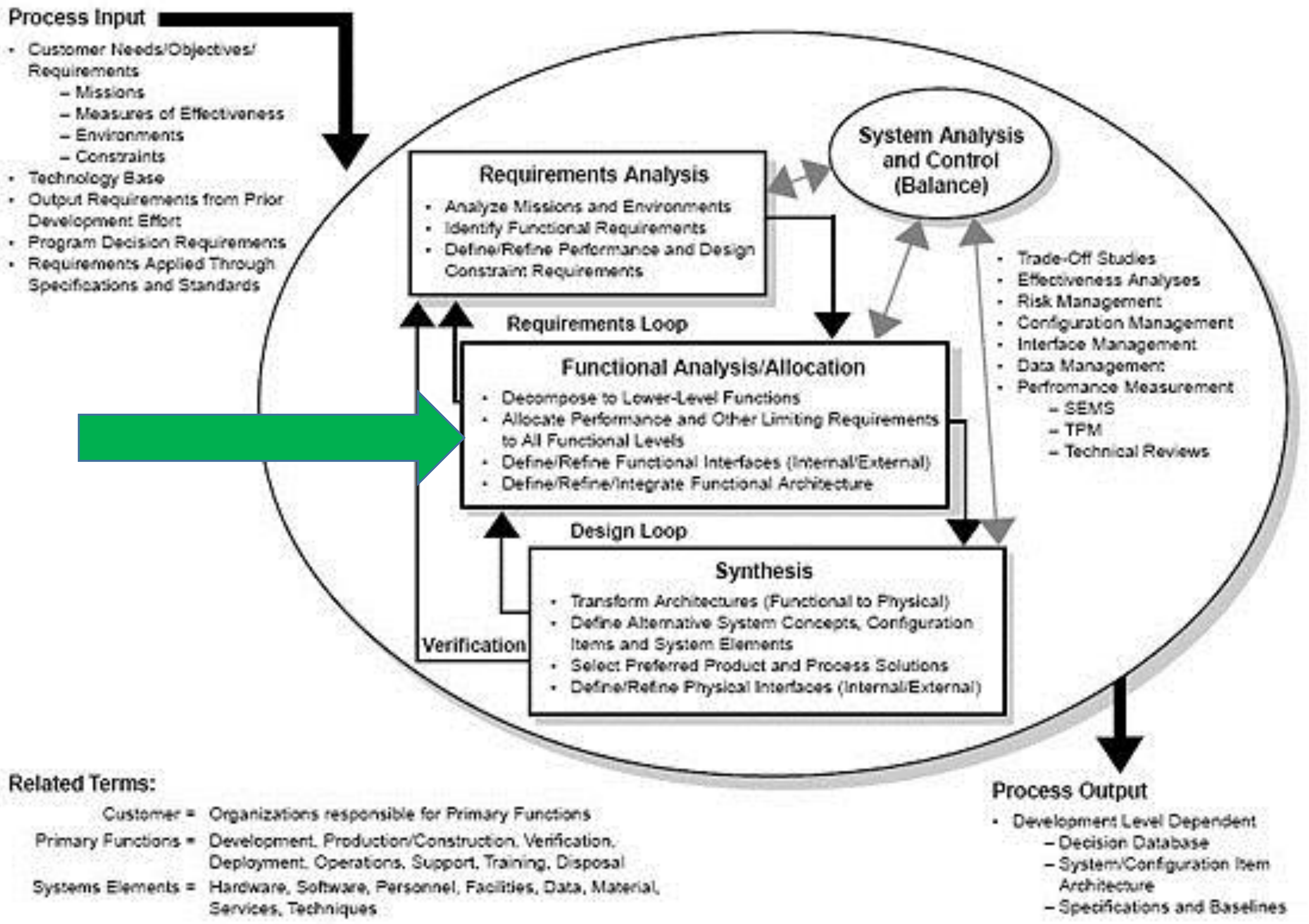


8. System Modeling & Simulation Analysis
9. Perform Trade Studies & Analysis
10. Define Technology Needs
11. Refine Design (Design Development)
12. Perform Cost Assessment
13. Rapid Prototyping, Testing, & Evaluations
14. Refine the Design

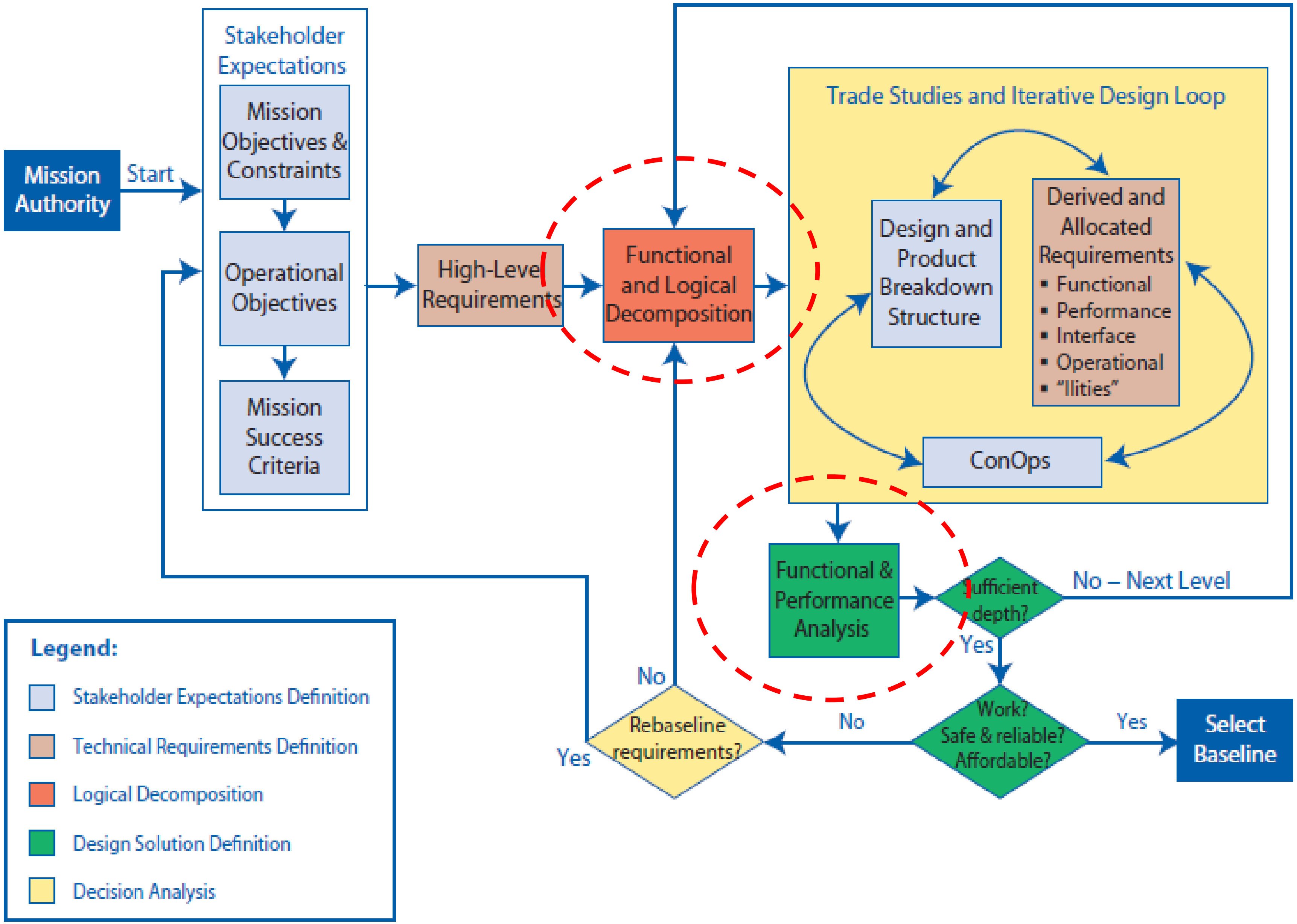
Human Systems Integration & Systems Engineering



Systems Engineering Process



Inter-relationship among System Design Process



Functional Definitions

- Functional Analysis: The process of identifying, describing, and relating the functions a system must perform to fulfill its goals and objectives.
- Functional Baseline: The functional baseline is the approved configuration documentation that describes a system's or top-level Configuration Item's performance requirements (functional, interoperability, and interface characteristics) and the verification required to demonstrate the achievement of those specified characteristics.
- Functional Decomposition: A sub-function under logical decomposition and design solution definition, it is the examination of a function to identify sub-functions necessary for the accomplishment of that function and functional relationships and interfaces.

Functional Decomposition

- Functional requirements define what functions need to be done to accomplish the objectives.
- Performance requirements define how well the system needs to perform the functions.
- Each function is identified and described in terms of inputs, outputs, and interface requirements from the top down so that the decomposed functions are recognized as part of larger functional groupings. Functions are arranged in a logical sequence so that any specified operational usage of the system can be traced in an end-to-end path to indicate the sequential relationship of all functions that must be accomplished by the system.

Functions

- Process:
  - Walk through the ConOps and scenarios asking the following types of questions:
  - what functions need to be performed,
  - where do they need to be performed,
  - how often,
  - under what operational and environmental conditions, etc.
  - Thinking through this process often reveals additional functional requirements.

Example of Functional and Performance Requirements

- **Initial Function Statement**
  - The Thrust Vector Controller (TVC) shall provide vehicle control about the pitch and yaw axes.
  - This statement describes a high-level function that the TVC must perform. The technical team needs to transform this statement into a set of "design-to" functional and performance requirements.
- **Functional Requirements with Associated Performance Requirements**
  - The TVC shall gimbal the engine a maximum of 9 degrees, ± 0.1 degree.

Habitation Operations

Crew Operations - IVA

Sustain crew on lunar surface for mission. These functions are necessary to insure the safety of the crew. It also includes providing the functions necessary to sustain the crew from a health and well being perspective.

Crew Operations – Supporting EVA

Enable Redundant EVA Function & Enhanced EVA Capability. These functions are necessary to provide the crew with additional means to conduct routine EVAs. The extent provided is driven by the mission duration and the number of EVAs required to conduct that mission.

Mission Operations

Enable Enhanced Mission Operations Capability. These functions are those that enable the lunar surface crew to conduct surface operations in concert with the Earth based mission control. For longer surface stays it should also establish autonomy from the Earth based "mission control" enabling command and control with other surface assets such as rovers, landers, etc.

Science Operations

Enable IVA Bio/Life Science & GeoScience Capability. These functions are necessary to conduct the science involved with the mission. It can include sample collection, sample analyses, sample prioritization and storage, and any sample return required. It also is meant to include any specific "environmental" requirements specific to Life Science or GeoScience

Logistics & Maintenance Operations - IVA & EVA

Enable Maintenance, Resupply, & Spares Cache. These functions are those that allows for maintaining the surface assets during recognized maintenance intervals. It also includes those functions necessary to resupply the habitat(s) with consumables (both pressurized and unpressurized) to support the crew for the mission. Lastly, it also includes the functions necessary to deliver and store the necessary spares related to the maintenance as well as unexpected failures.

Example: Exploration Habitat Functionality

Discipline	Function Title
Structures	Human-Rated Pressurized Volume
	System Volume
	Habitable Volume
	Stowage Volume
	Internal and External Loads
	Micrometeoroid Protection
	Inter-module Viewing (through hatch)
	Extra-Vehicular Activity (EVA) Translation Aids
	Grapple Fixtures and Robotic Accommodations
	Structural Health Monitoring
Mechanisms	IDSS-compliant Docking and Undocking
	Robotic Lander Berthing Capture and Structural Mating
	Hatches for Crew and Cargo
	Electrical Bonding
	Transfer of Air, Data, and Power
Power	Power Distribution
	Power Storage
	Power Management
	Power Quality Conditioning and Conversion
Thermal	Passive Thermal Control
	External Component Thermal Control
	Internal Component Liquid Cooling
	Cabin Air Cooling and Condensation Control
	Avionics Air Heat Rejection
	Heat Rejection

Discipline	Function Title
ECLSS (Air)	Cabin Air Humidity Control
	Air Circulation within Modules
	Air Circulation between Modules
	Cabin Air Trace Gas Contaminants Control
ECLSS (Env Monitor)	Major Constituent Gases (O_2, CO_2, H_2O, and N_2 or Pressure) Measurement
	Cabin Air Trace Gases Measurements for Nominal Levels
	Cabin Air Trace Gases Measurements for Non-Fire Contingency Events
ECLSS (Waste)	Trash and Waste Stowage
Fire Safety	Detect Fires
	Suppress Fires
	Measure Trace Gases in Cabin Air from Combustion or Pre-combustion Off-nominal Events
Crew Systems	Vehicle Lighting
	Intra-Vehicular Activity (IVA) Translation Aids
	In-situ Active Space Radiation Crew Effective Dose and Dose Rate Measurements

Discipline	Function Title
Avionics/ FSW	Sensor and Effector Data Collection and Transmittal
	Audio System that supports Caution and Warning Annunciation
	Flight Software Execution and Data Processing
	Ground Commanding and Telemetry
	Crew Displays and Controls
	Data Storage
Comm	Element to Element Communication Hardline
GN&C	Rendezvous and Berthing/Docking Sensors
	Rendezvous and Berthing/Docking Targets
Imagery	Imagery from Internal Fixed and Hand-Held Cameras
	Imagery from External Fixed and EVA Helmet Cameras
EVA	EVA to Vehicle Interfaces (EVA wireless comm)
	EVA Egress or Ingress
Science	External Science and Research Accommodations
Robotics	Enabling EVR Maintenance Tasks

example: Additional Functions

Discipline	Function Title
Power	Power Distribution
Avionics/ FSW	Crew Displays and Controls
ECLSS (Air)	Cabin Air Particulate Control
	Cabin Carbon Dioxide Removal
ECLSS (Env Monitor)	Cabin Air Particulate Measurements
ECLSS (Water)	Crew Potable Water Distribution and Dispensing
	Maintain Safe, Low Levels of Microbial Life in Potable Water
	Maintain Safe, Low Levels of Microbial Life in Waste Water
	Cold Water Dispensing
	Potable Water Storage for Crew Use
	Fluids Transfers between Storage Locations (CWC)
ECLSS (Waste)	Crew Urine Collection and Addition of Required Pretreat
	Crew Feces Collection
	Microbial Safety Control
	Trash and Waste Stowage
Crew Systems	Crew Medical Care
	Private Crew Quarters (4)
	Private Crew Waste Compartment
	Food Preparation
	Crew Dining
	Private Communications (in sleep quarters)

Human Exploration Systems

Elements

- Crew Return Vehicle
- Deep Space Habitat (DSH)
- Space Exploration Vehicle
- EVA Capability (Airlock)
- Propulsion Bus
- Power Generation & Storage Bus
- Thermal Rejection System (Radiators)
- Deep Space Communications
- Docking System(s)
- Robotics
- Logistics & Spares Resupply/Storage
- Maintenance and Repair

Human Exploration Systems

Exploration Habitat Systems

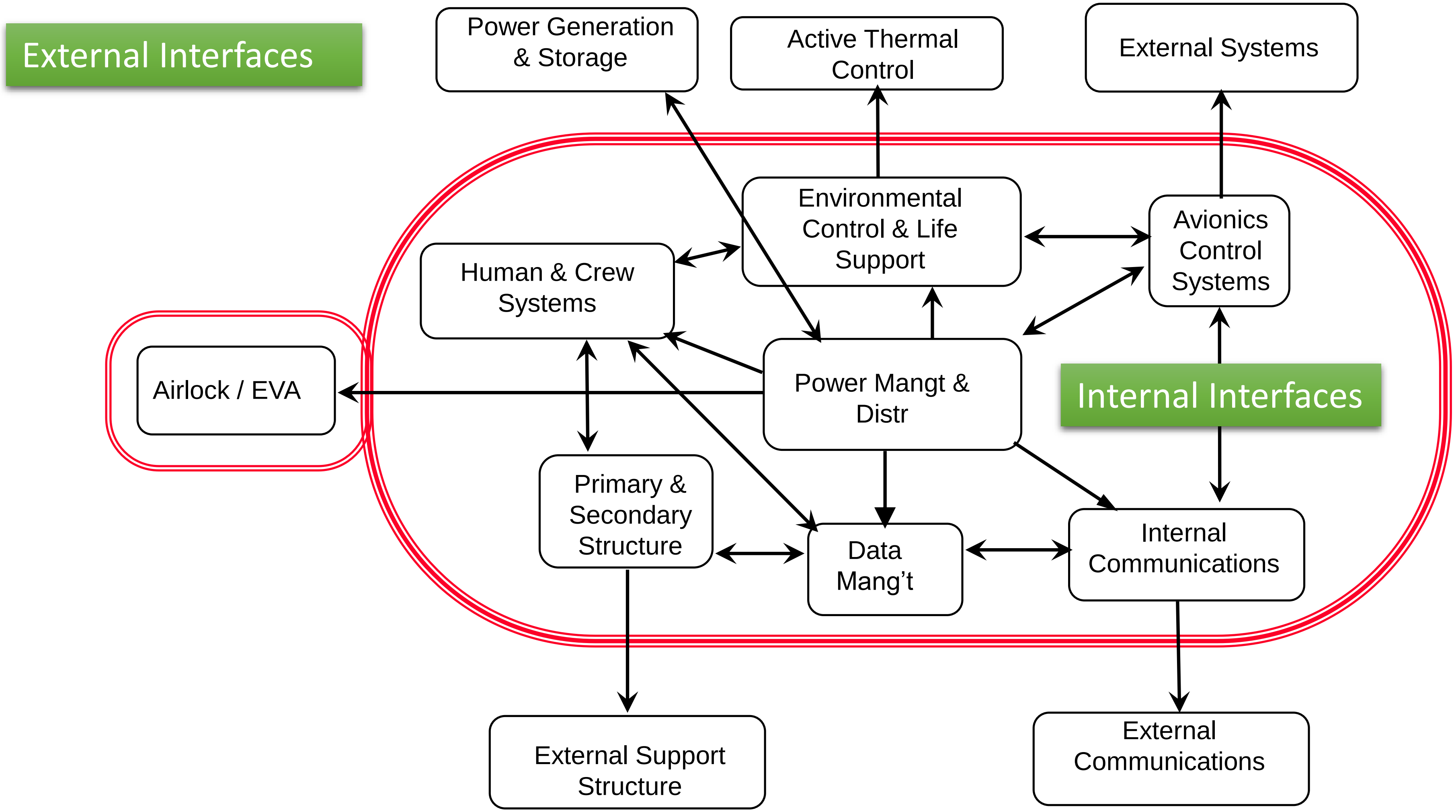
- Structures & Mechanisms
- Environmental Protection
- Life Support (ECLS)
- Power Management & Distribution
- Avionics (C&DH)
- Communication & Tracking System (GNC)
- Thermal Control System (Passive & Active)
- Crew & Medical Systems
- Laboratory Systems (Science & Research)
- Logistics, Repair, & Manufacturing
- EVA Support
- Robotics

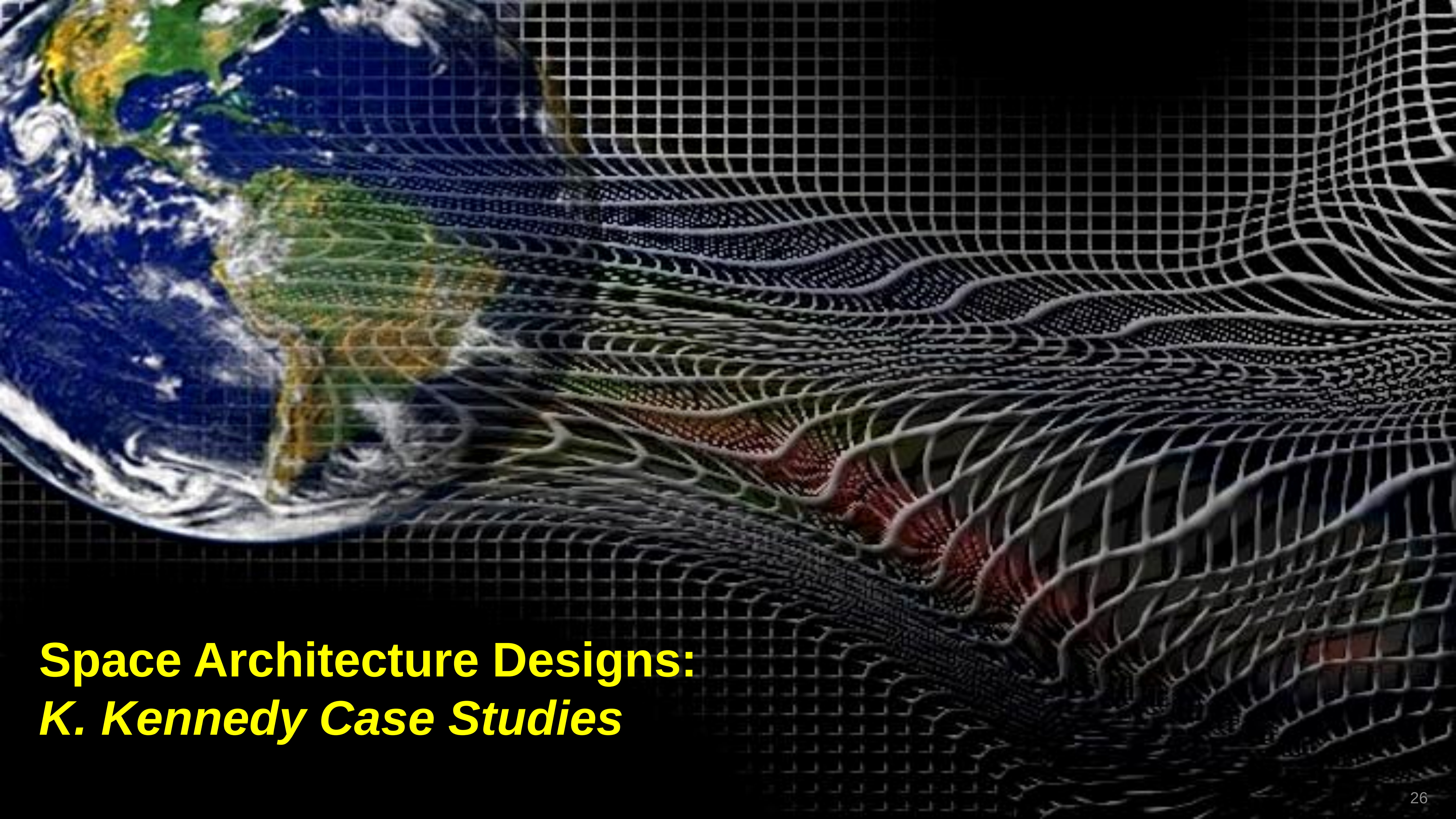
Interfaces

Interface Requirements

- It is important to define all interface requirements for the system, including those to enabling systems. The external interfaces form the boundaries between the product and the rest of the world.
- Types of interfaces include:
  - operational command and control,
  - computer to computer,
  - mechanical,
  - electrical,
  - thermal,
  - data.
- One useful tool in defining interfaces is the context diagram (see Appendix F), which depicts the product and all of its external interfaces.
- Once the product components are defined, a block diagram showing the major components, interconnections, and external interfaces of the system should be developed to define both the components and their interactions.

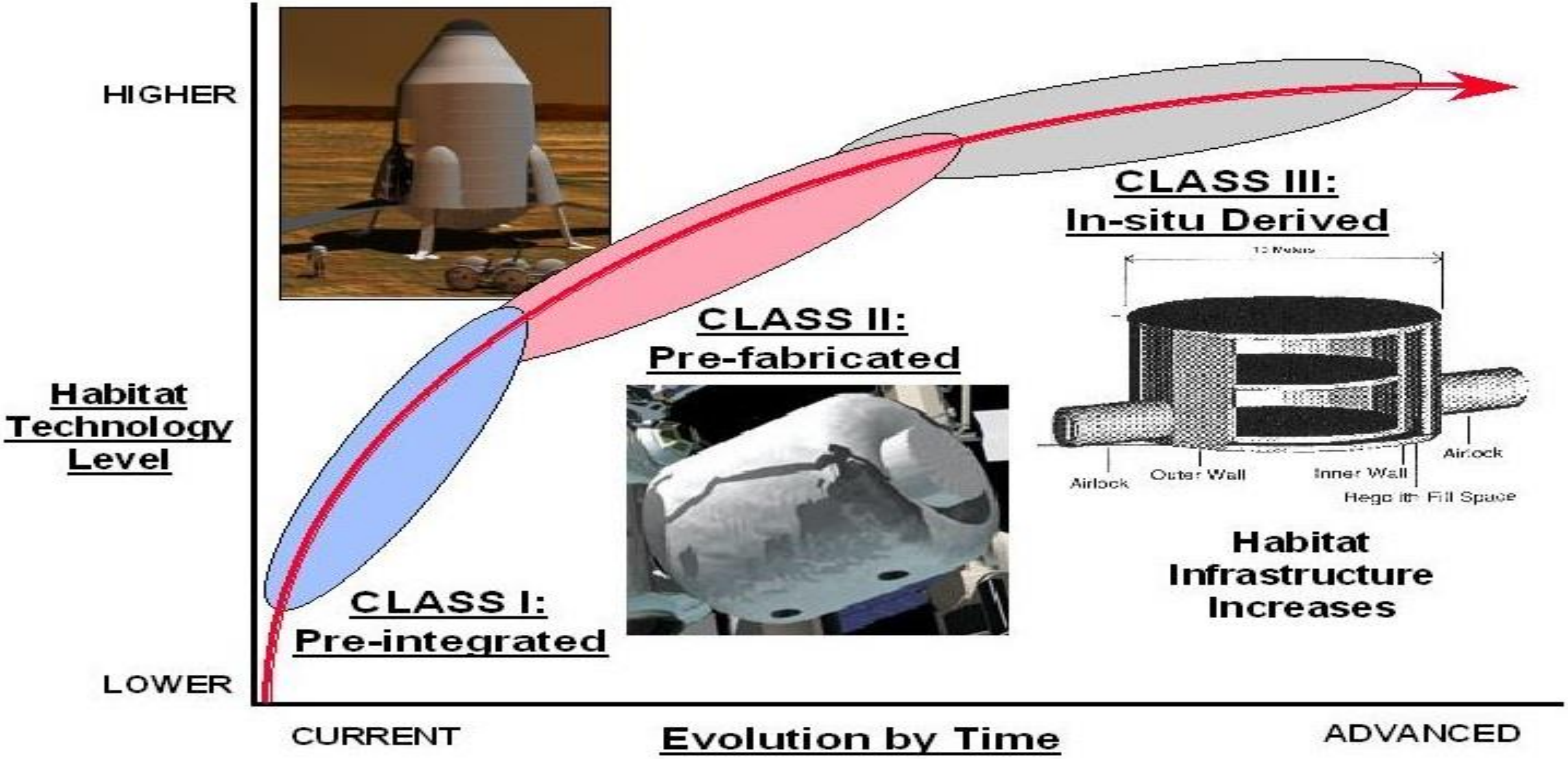
Habitation Elements & Interfaces



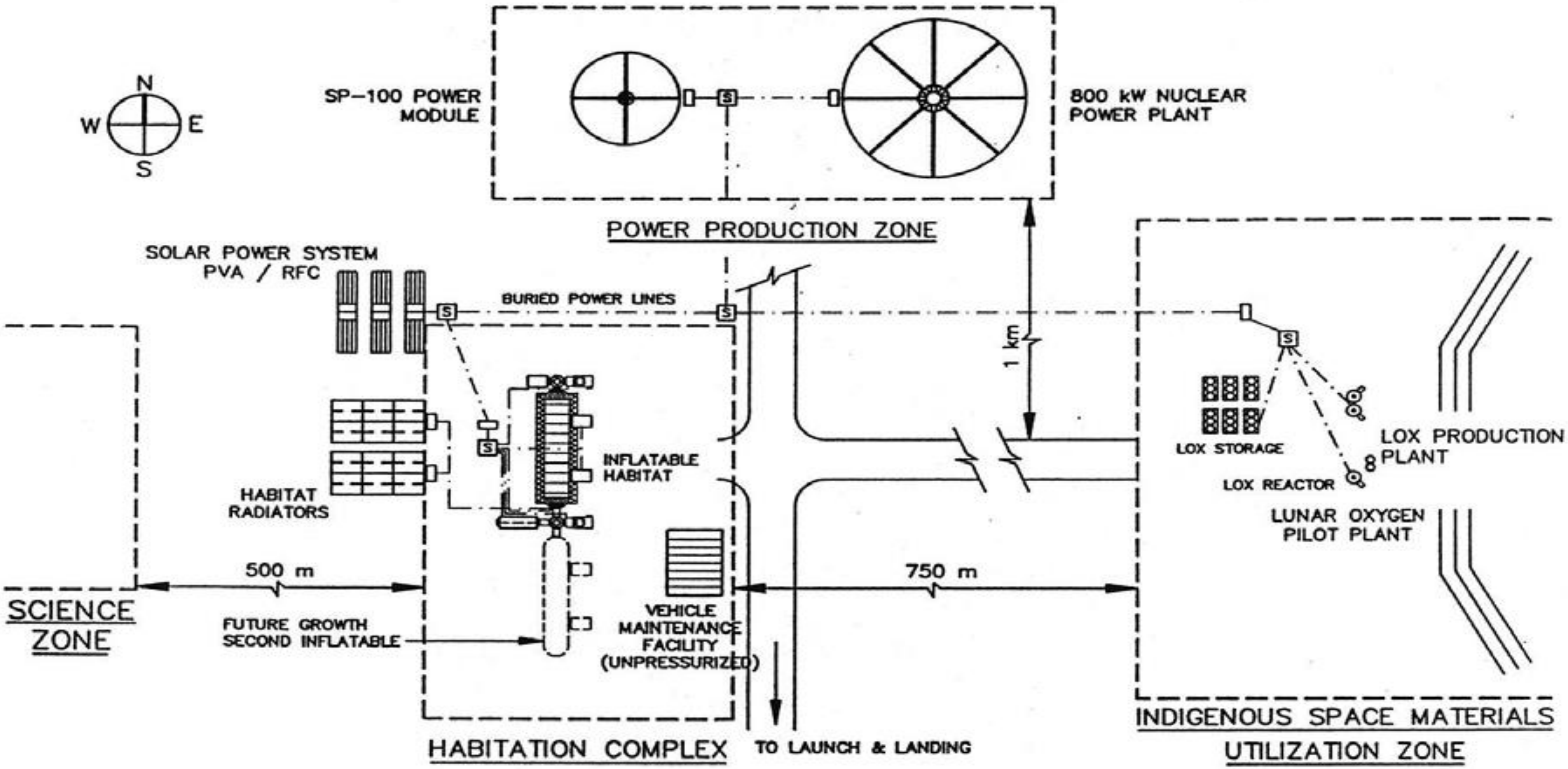


Space Architecture Designs:
K. Kennedy Case Studies

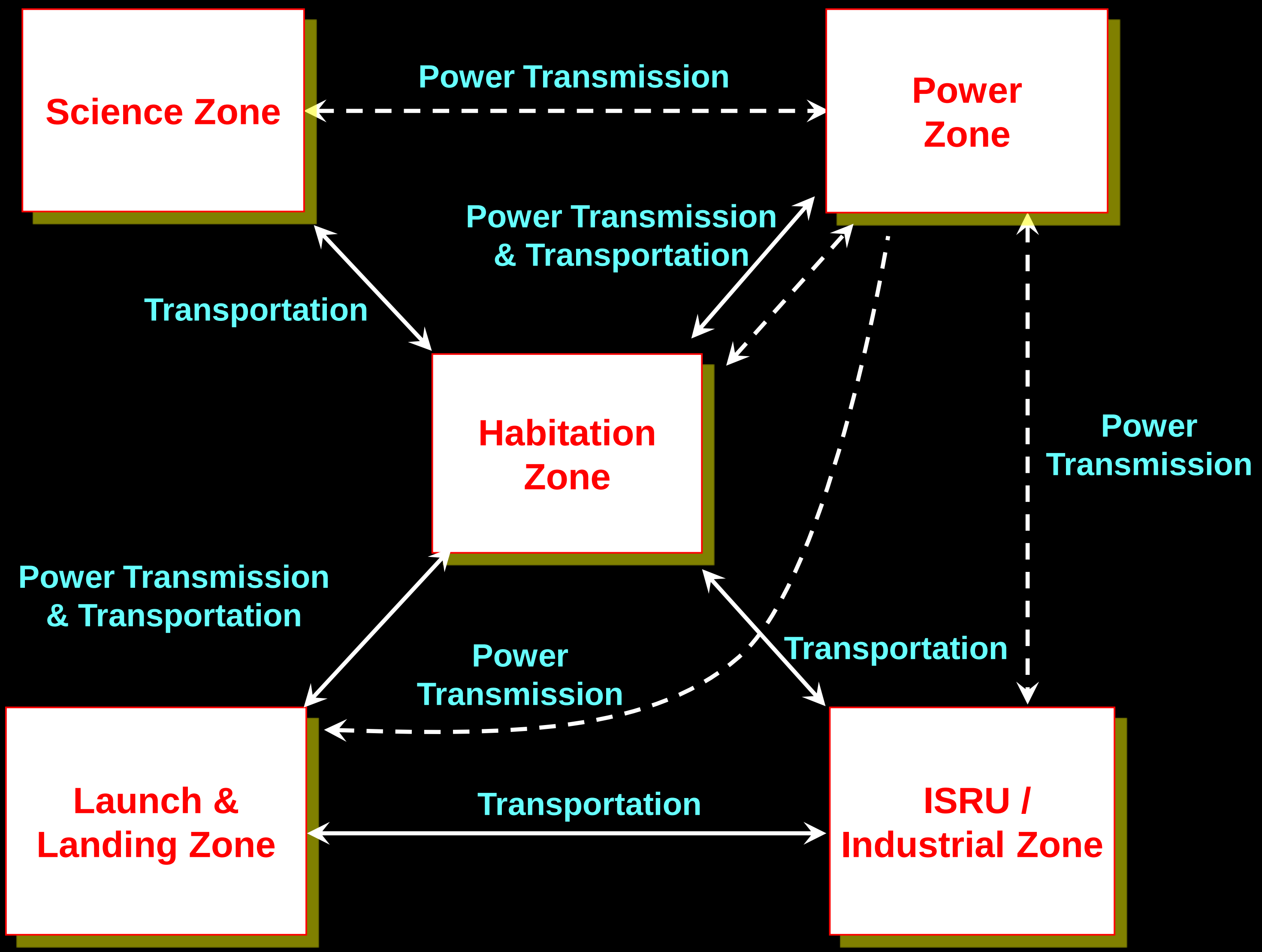
Space Habitat Classifications



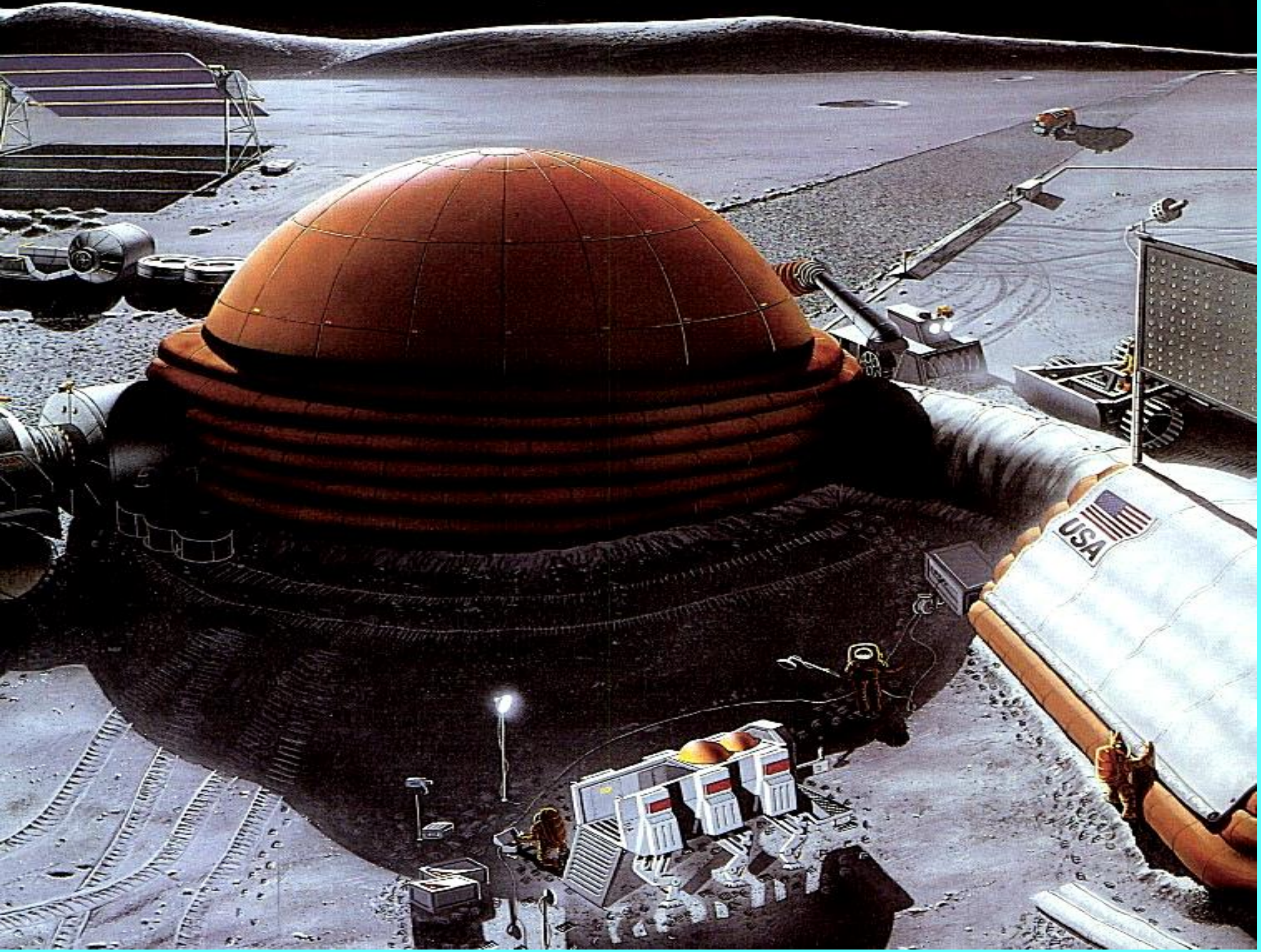
Lunar Surface Base Concept - 1988



Surface Outpost Organization & Zoning



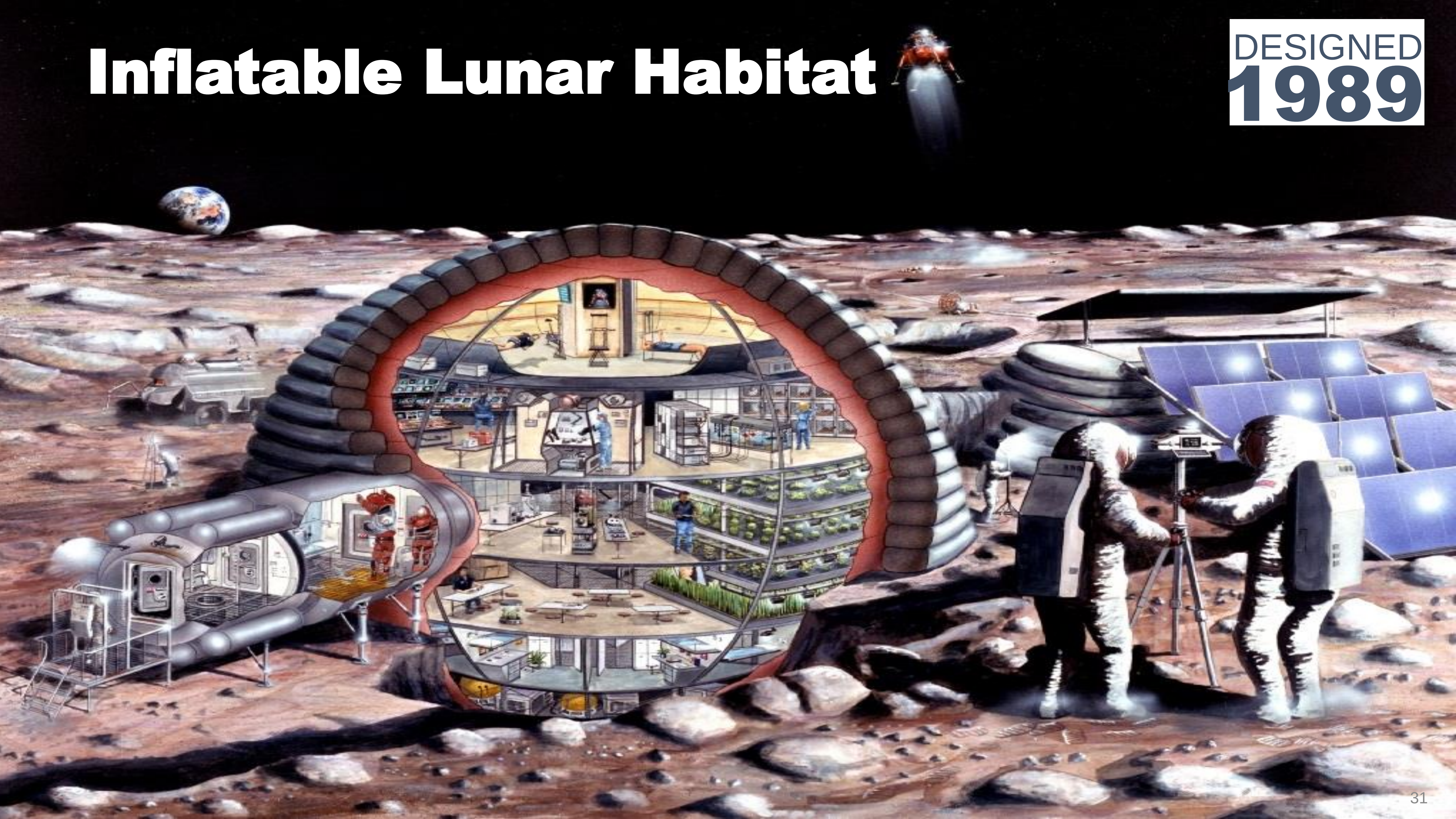
Inflatable Lunar Habitat



DESIGNED
1989

Inflatable Lunar Habitat

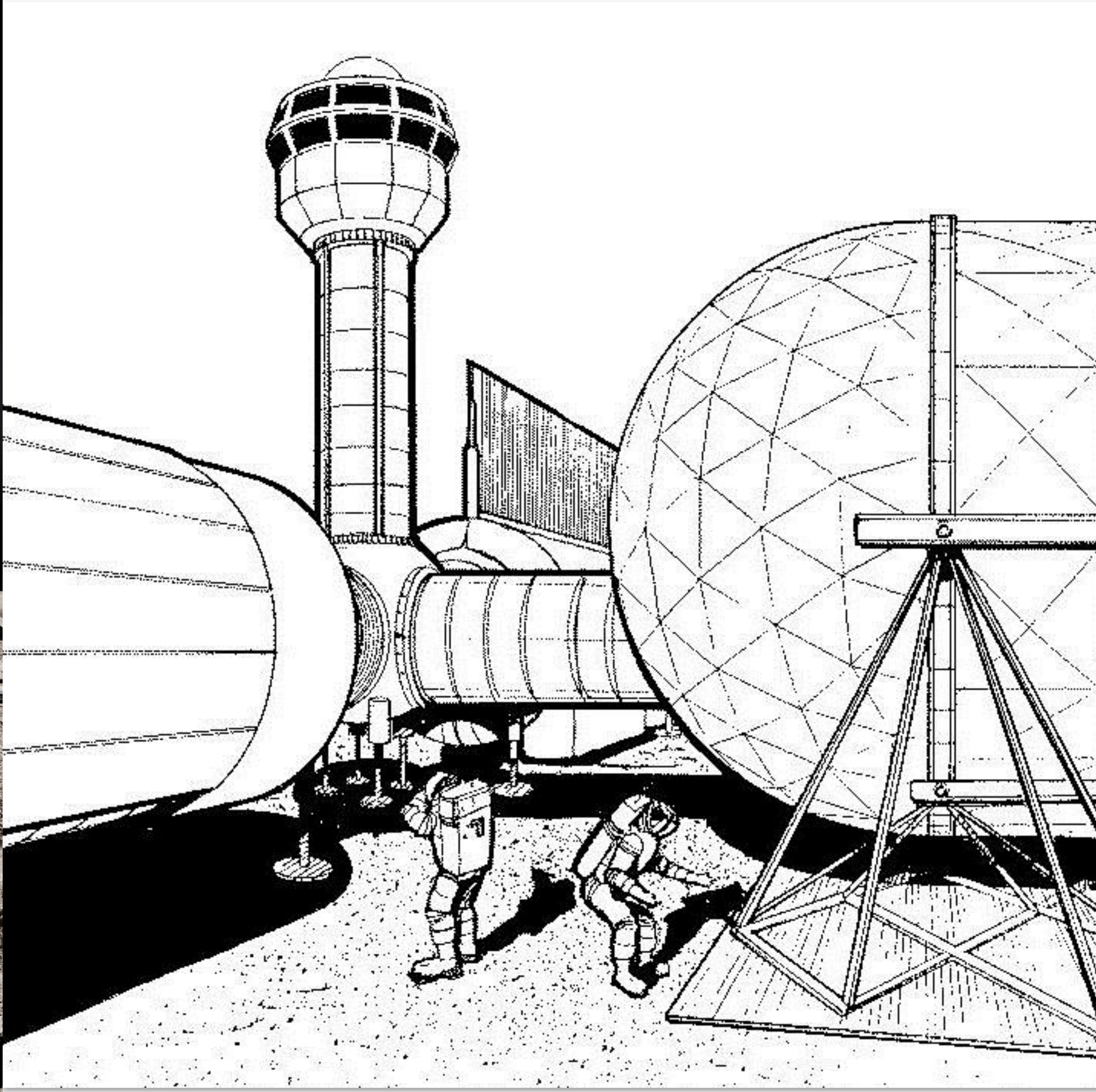
DESIGNED
1989



Inflatable Lunar Habitat

DESIGNED
1992

Inflatable Lunar Habitat



Mars Robotics Sample Return

DESIGNED
1994

Lunar Excursion Vehicle

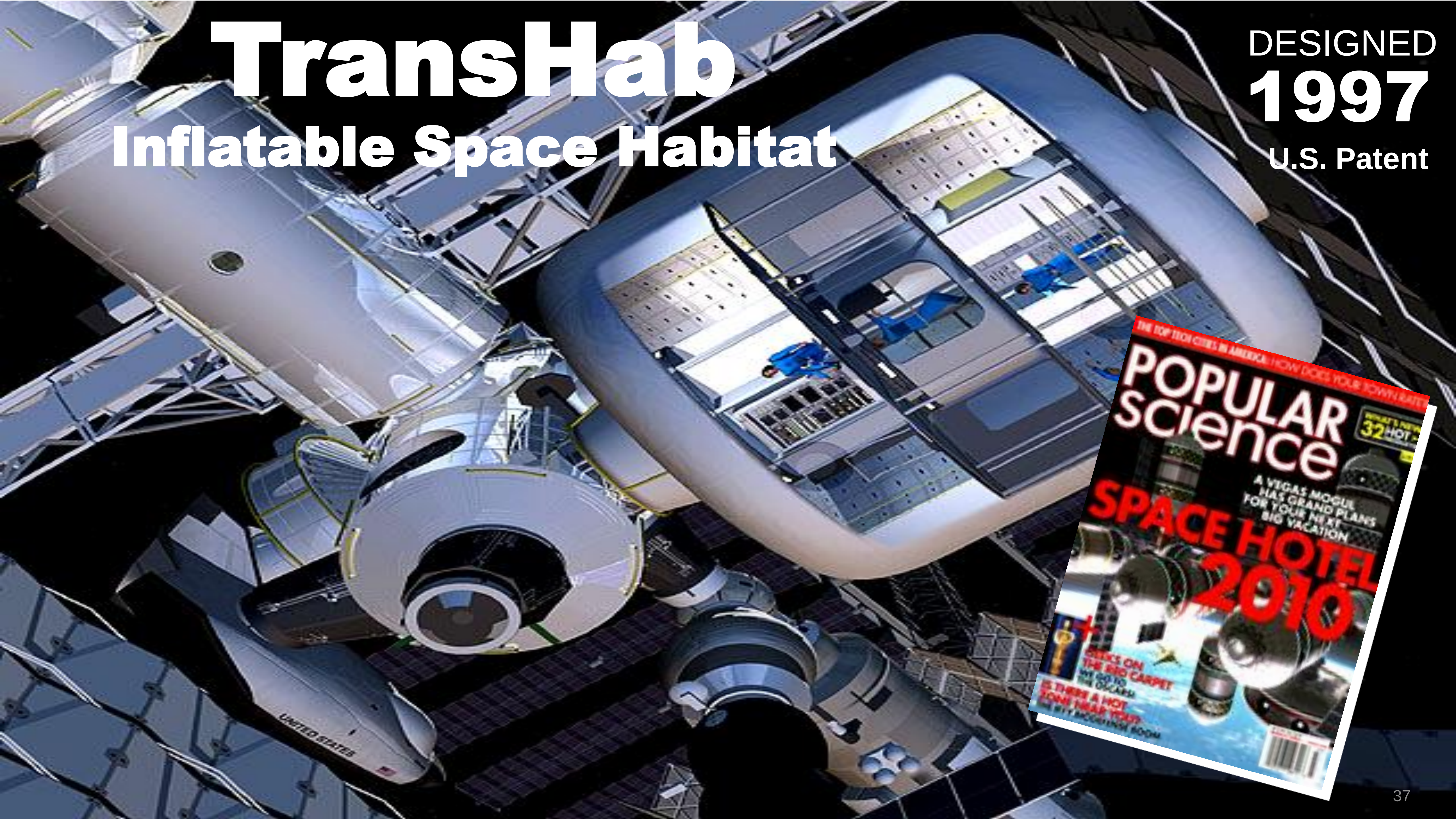
DESIGNED
1995

Mars Base & Mission Planning 1996

TransHab

Inflatable Space Habitat

DESIGNED
1997
U.S. Patent

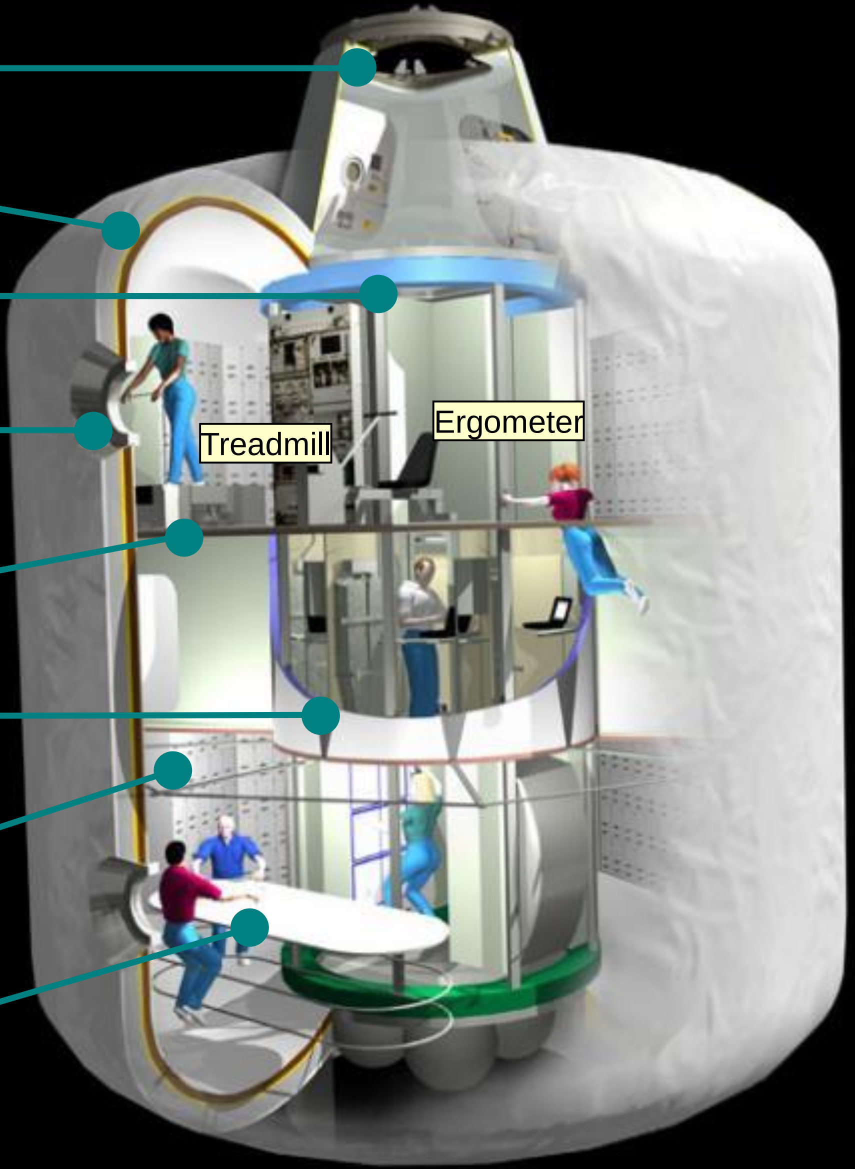


ISS TransHab

Full Scale Shell Development Unit (SDU-3)

First Inflation: November 17, 1998

ISS TransHab Architecture



Hatch Door

Inflatable Shell

Central Structural Core

20” Window (2)

Inflatable Outfitting Compression Ring

Integrated Water Tank

Soft Stowage Array

Wardroom Table

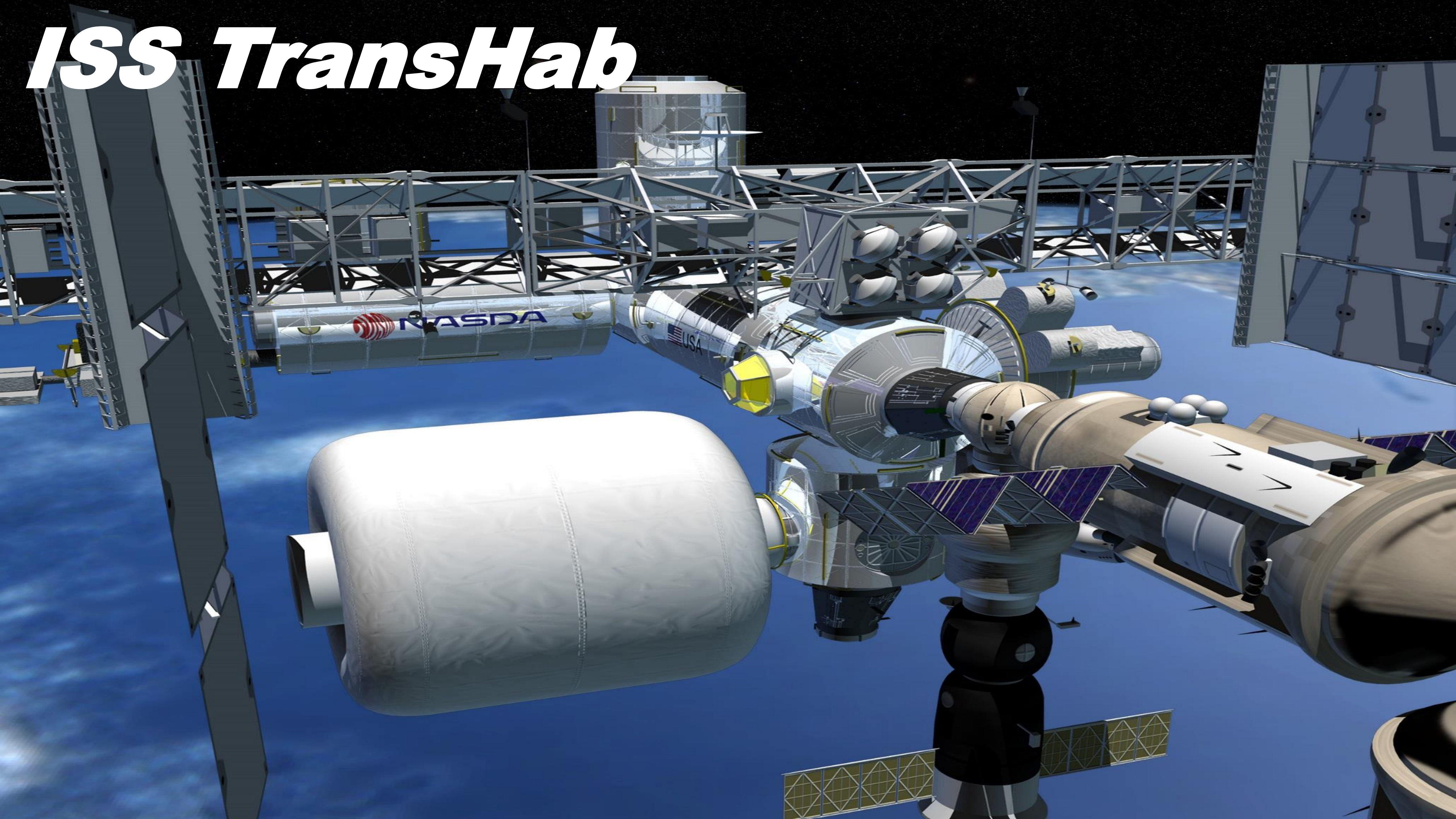
Level 4: Pressurized Tunnel

Level 3: Crew Health Care

Level 2: Crew Quarters and Mechanical Room

Level 1: Galley and Wardroom

ISS TransHab



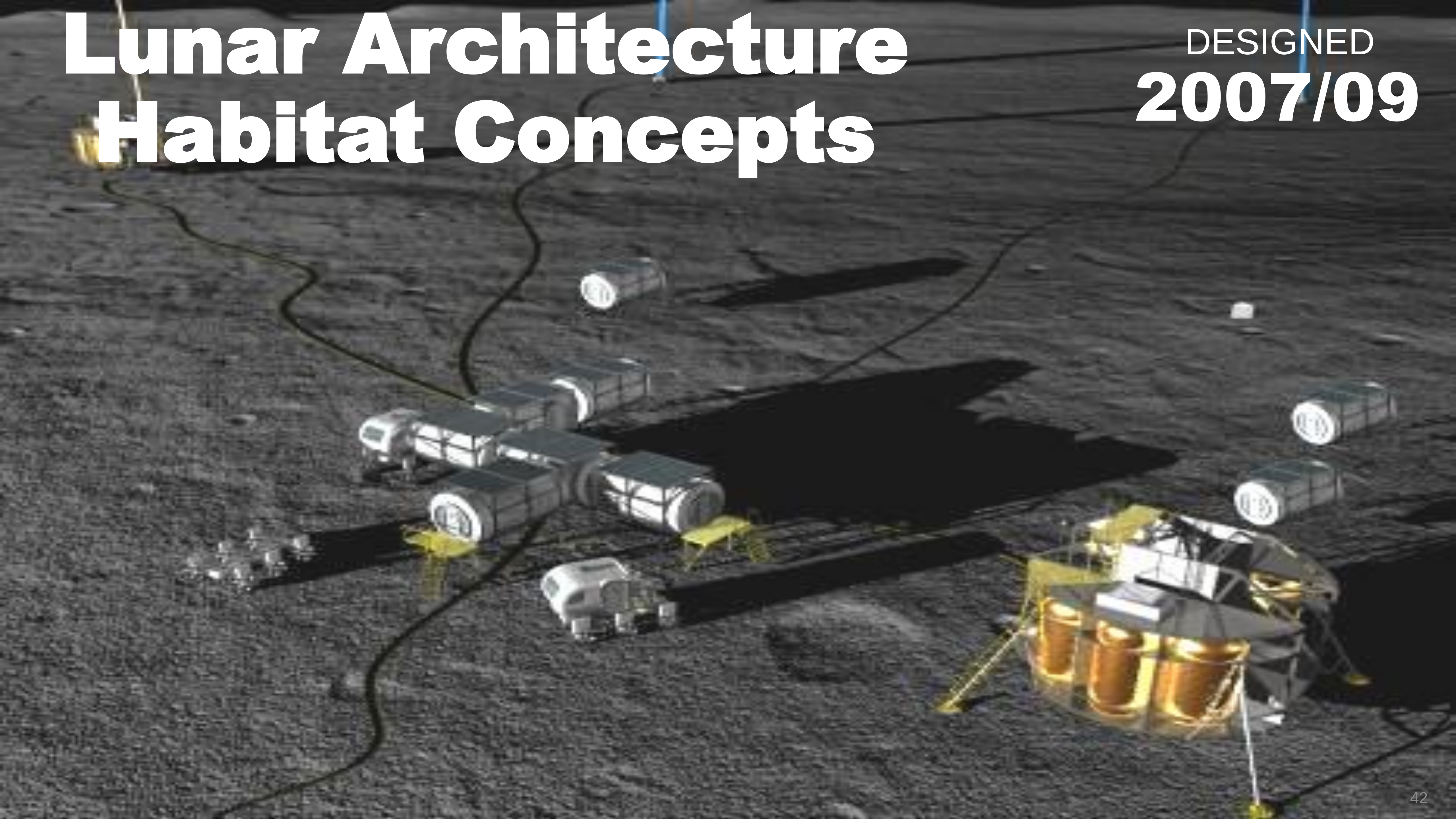
Mars Surface Hab/ Combo Lander

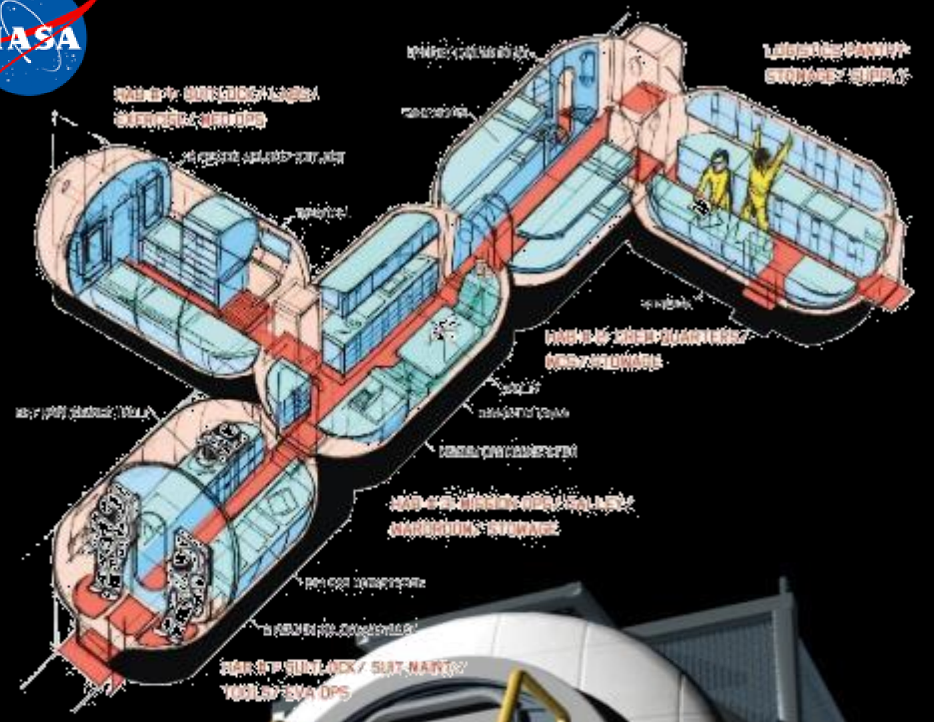
DESIGNED
2000

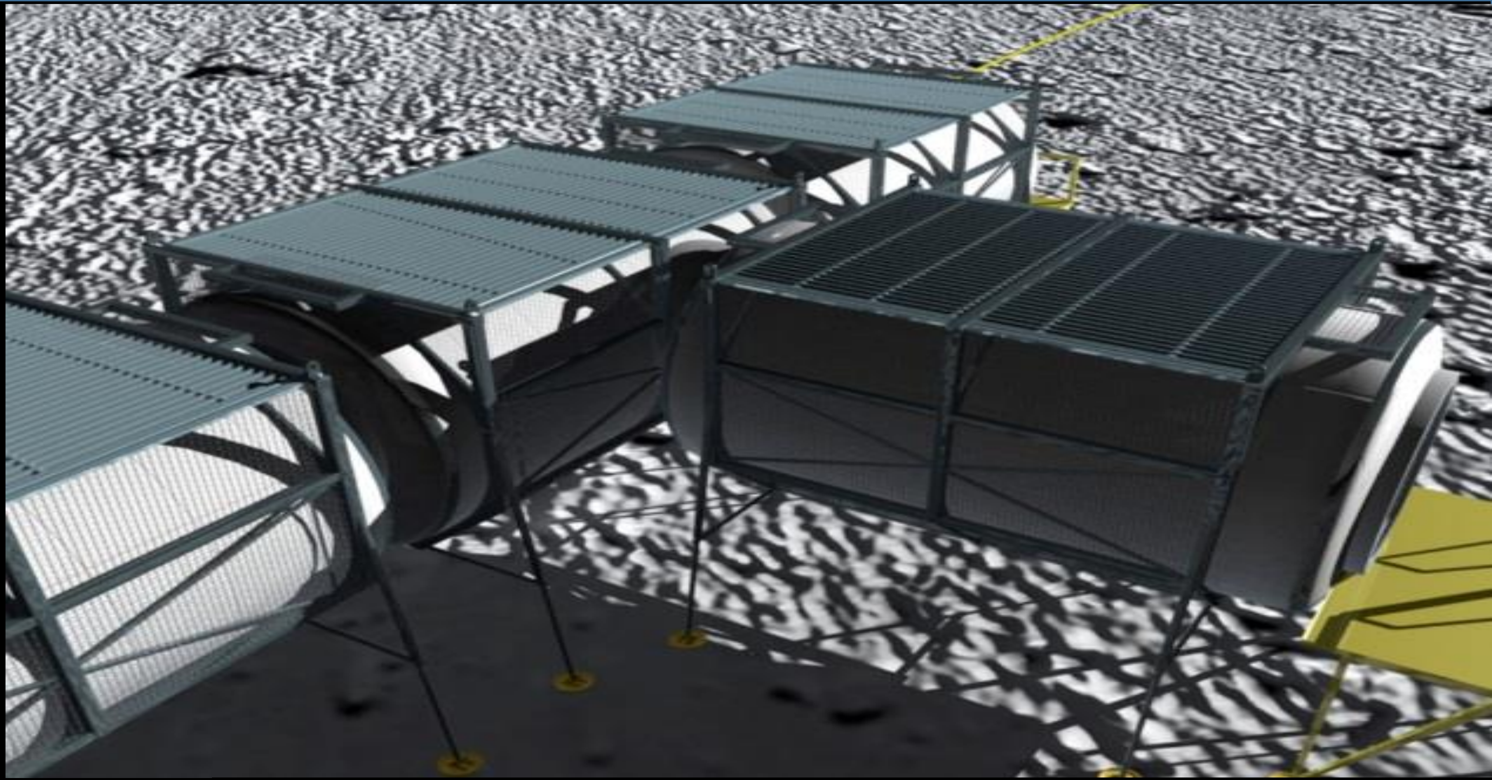
Lunar Architecture Habitat Concepts

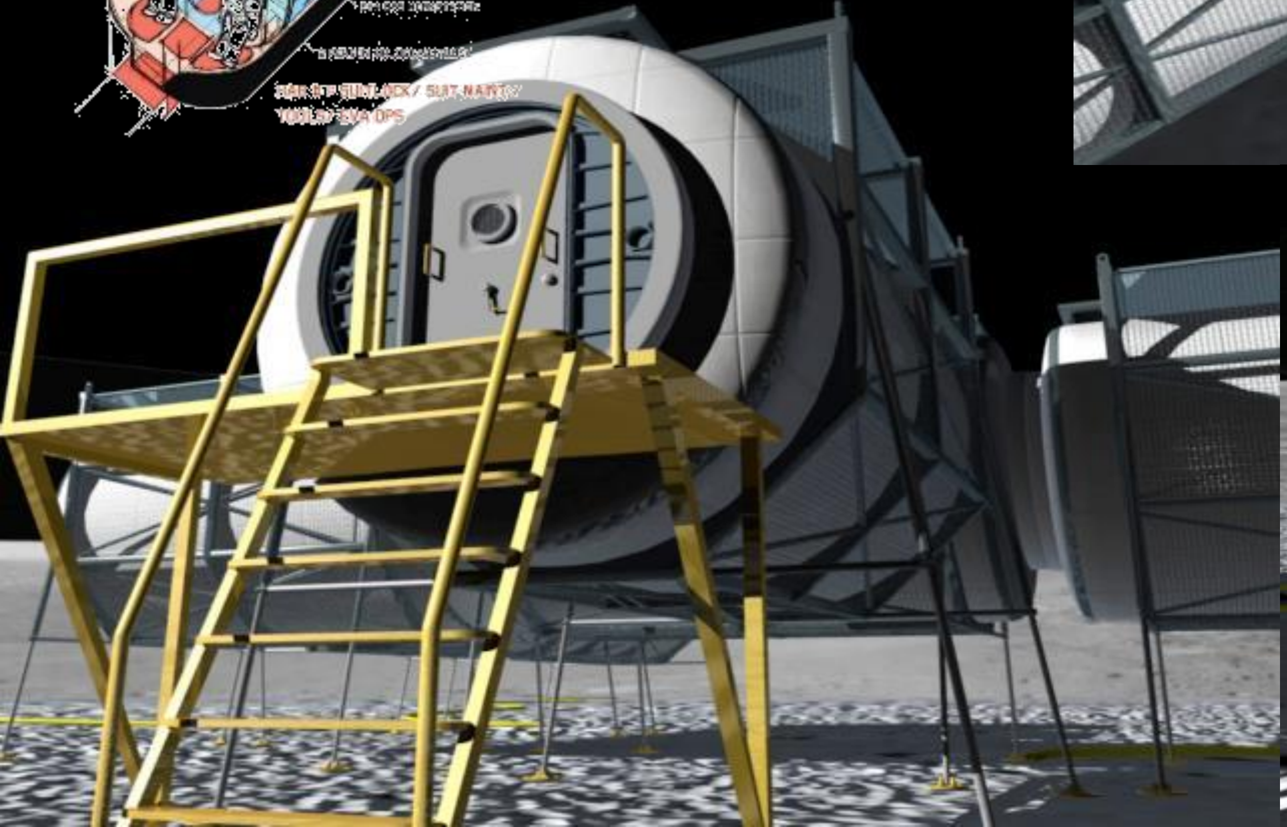
DESIGNED

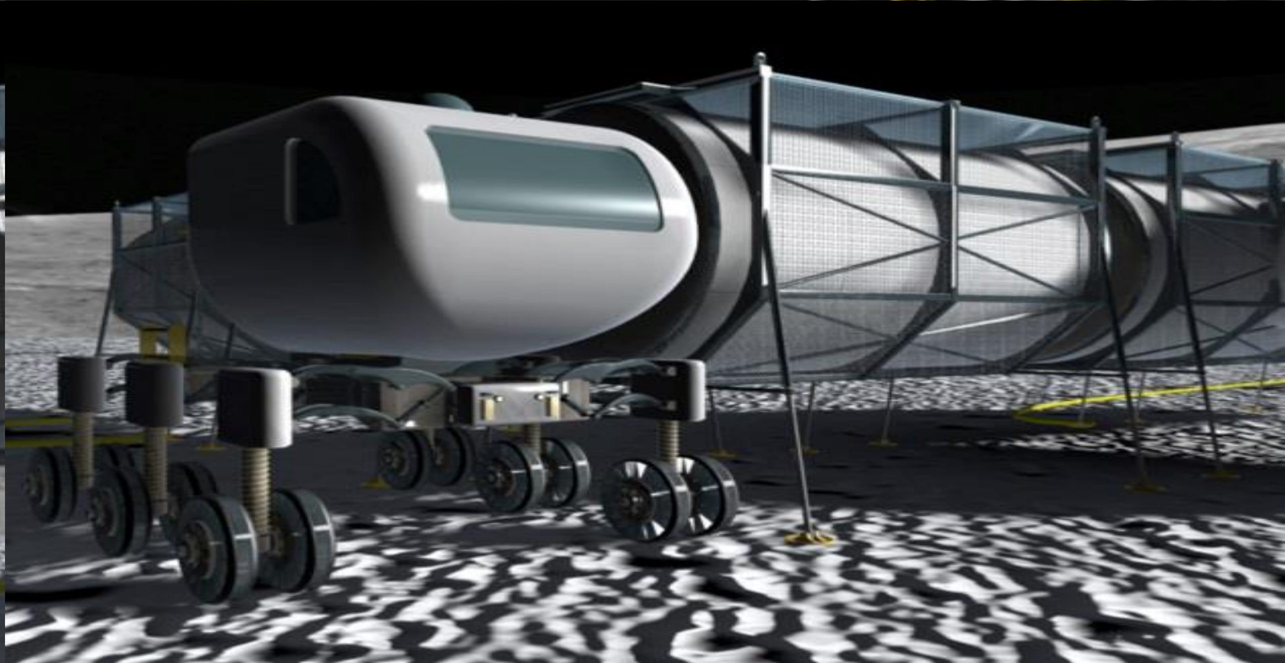
2007/09





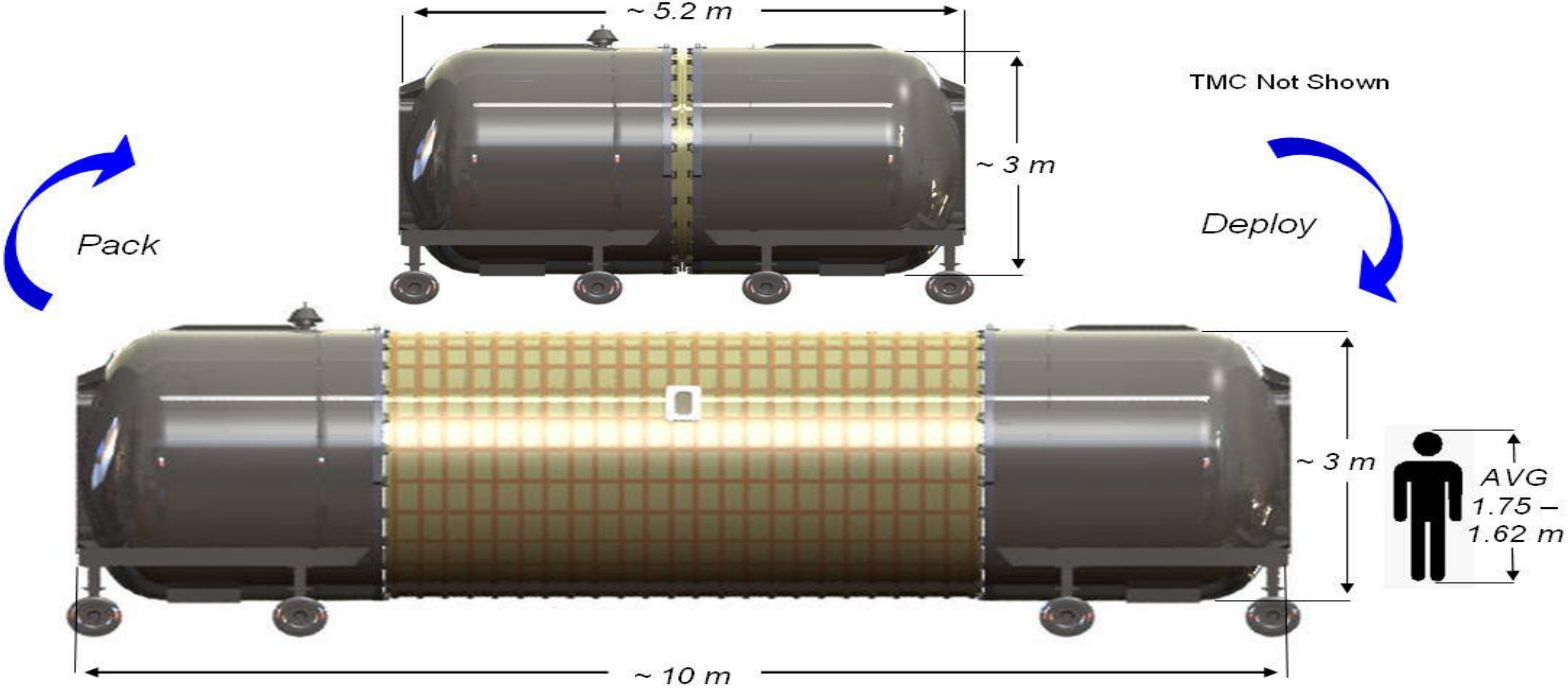






Mid-Expandable Habitat

DESIGNED
2008

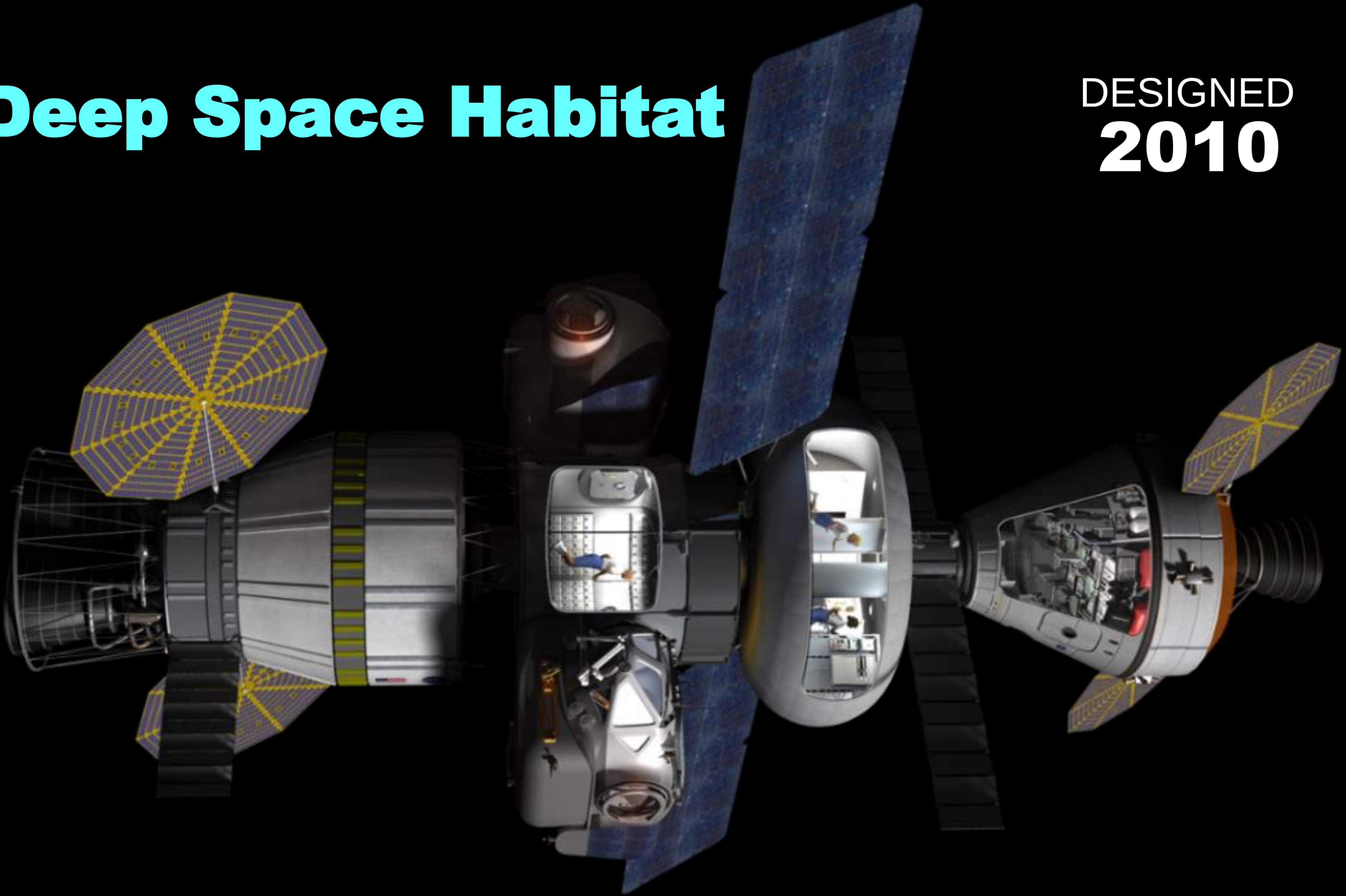


Pressurized Excursion Module

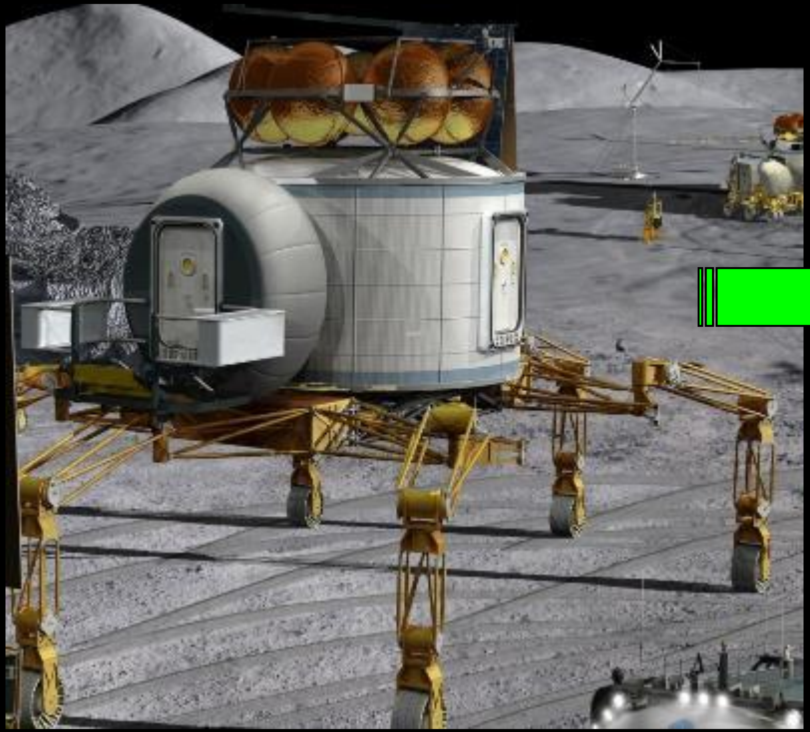
DESIGNED
2009

Deep Space Habitat

DESIGNED
2010



Habitat Demonstration Unit



June 2009

June 2010

RAPID PROTOTYPING

HDU

Habitat Demonstration Unit

Earth Analog Testing

Habitat Demonstration Unit


AIRLOCK
RETURN AIR

Exploration Habitat Academic Innovation Challenge

Started
2010

X HAB
ACADEMIC INNOVATION
CHALLENGE

Deep Space Habitat Inflatable ‘Loft’ 2011

Space Architecture...

...architecting the future

www.spaceflight.nasa.gov

www.nasa.gov